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## VECTORS Final Report

### VECTORS

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# VECTORS Final Report

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## Project Summary

**VECTORS has provided new knowledge to help govern and manage our seas in a holistic and considered way, putting the impacts the oceans have on humans at the centre of decision making**

Marine life makes a substantial contribution to the economy and society of Europe. In reflection of this, VECTORS has been a substantial EU funded project with 38 partner institutes. Through interdisciplinary and integrated research it has addressed changes in marine life, such as changes in distribution and productivity of fisheries, increases in outbreaks of organisms such as jellyfish blooms, and increasing invasions of alien species, with case studies to support generic understanding in the Western Mediterranean, North Sea and Baltic Sea.

VECTORS has elucidated many of the drivers, pressures and vectors that cause changes in marine life, the mechanisms by which they do so, the impacts that they have on other parts of the marine ecosystem and its functioning, the services these ecosystems provide, and the social and economic consequences for associated marine sectors and society. New and existing knowledge and insight has been synthesized and integrated to project future changes in marine life, ecosystems and economies under different scenarios for adaptation and mitigation.

As understanding has increased during the project, VECTORS has evaluated current forms and mechanisms of marine governance in relation to the vectors of change working in consultation with key policy and marine sector stakeholders to understand their needs and the implications of VECTORS findings for them. Policy recommendations for governance controls have been made. For example, future governance should focus on activities where there is little or no current regulation, such as sectors of the Blue Growth agenda (e.g. large scale offshore aquaculture, seabed mining, blue biotechnology) and little is known about the ecosystems in which the activities take place.

VECTORS has developed tools to support the development of strategies to mitigate and respond to marine life changes, these include:

- » Specialised databases and tissue repositories for invasive alien and outbreaking species.
- » An iPhone app for informing on the occurrence of jellyfish blooms.
- » Novel use of risk assessment approaches which have been applied to case studies of marine renewable energy and fisheries.
- » Risk assessment and decision support systems for ballast water management.
- » Suites of modelling tools for ensemble analysis of ecological, ecosystem, fishery and economic change in response to management strategies.
- » Development and implementation of Atlantis, a cross sector framework model, for the first time in the EU waters for management strategy evaluation particularly of multiple stressors.
- » Novel application of global models to understand the macro-economic implications of marine life change.





Project results are multiple, a selection of which are provided here.

Climate change and interactions between different marine sectors are causing changes in marine life in all three regional seas with the rate of invasion by new species currently greatest in the Mediterranean.

The distribution of many fish and invertebrate species is projected to move northwards over the next 50 years in response to anticipated climate change. Tradition, as well as economic opportunity, drives fishermen's allocation of effort but the impacts of competition for space with other marine sectors varies among fleets and seas.

Impacts of changing marine life on ecosystems, their functioning and provision of services are diverse and dependent upon context. Nonetheless, the public place value on aspects of ecosystems representing marine ecosystem services, with conservation and the protection of the environment recognized as important as long as they are in balance with economic uses.

Jellyfish outbreaks have an economic and social cost to tourists in the Mediterranean, yet jellyfish also have potential benefits as a commodity in nutrition and pharmaceuticals. There are economic effects of marine life change in fisheries, tourism and shipping sectors but effects on fisheries profitability are not consistent across regional seas or fish stocks within seas.

Spatially explicit models have now been developed that can analyse management strategies for multi-species stocks of fish and for spatial interactions between maritime sectors and management measures for conservation. Macro-economic impacts of changes in marine ecosystems on EU countries are greater when tourism is affected because it has a much higher contribution to the production of value added than fisheries.

VECTORS research results can be found on the synthesis website <http://www.marine-vectors.eu/> which provides a tool for stakeholders, marine managers and policymakers and advisors to access VECTORS knowledge for use in support of marine management decisions, policies and governance.

All of VECTORS detailed deliverable reports as well as the scientific publications from the research can be found on the web site at [www.marine-vectors.eu](http://www.marine-vectors.eu)

## Project Context and Objectives

**VECTORS aimed to provide data, innovative models and decision support tools to relevant stakeholders within the environmental, policy and economic spheres.**

Human use of the European marine environment is increasing and diversifying. This is creating new mechanisms for human induced-changes in marine life which need to be understood and quantified as well as the impact of these changes on the ecosystem, its structures (e.g. biodiversity) and function (e.g. food chain), and the social and economic consequences that then arise. The current and emerging pressures are multiple and interacting including impacts from transport, energy devices, exploitation of living resources, discharges, together with environmental changes (including climate change). Anticipating the future consequences of these pressures and vectors of change in marine life and of adaptation and mitigation measures (such as the introduction of new technologies and structures, new ballast water practices, ocean and offshore wind energy devices and new fishing strategies) is prerequisite to informing development and implementation of forthcoming strategies, policies and regulations, such as the IMO Convention on ballast water management and the EU Maritime Policy and Marine Strategy Framework Directive.

The VECTORS project sought to develop integrated, multidisciplinary, research-based understanding that will contribute the information and knowledge required for addressing forthcoming requirements, policies and regulations across multiple sectors. VECTORS aimed to provide data, innovative models and decision support tools to relevant stakeholders within the environmental, policy and socio-economic spheres. To achieve this it employed a combination of policy and sector analysis, data synthesis, comprehensive statistical analysis, targeted experimentation, social and economic valuation, and ecosystem and economic modelling along with regular and in-depth stakeholder consultation and interaction. VECTORS promoted the application of its tools and knowledge throughout the lifetime of the project, aiming to seek outcomes from the research as well as outputs, culminating in the production of a synthesis website of the project's findings.

The clear aim was to deliver genuinely integrated interdisciplinary research (rather than aspects broadly moving in the same direction but with limited interaction). Given the complex nature of the marine environment, its multiple stresses and multiple ecosystem responses, VECTORS focussed on specific areas of concern identified at the outset by the EC: outbreaks of invasive or indigenous species, changes in the distribution of populations of marine organisms, such as fish populations, the vectors of these changes, and the impacts of these changes on biodiversity and related maritime economic sectors. The approach was to develop generic understanding and apply and test it through three case study regional seas (Western Mediterranean, North Sea and Baltic Sea). The VECTORS outputs are thus relevant and valuable to other regional seas.

The VECTORS project addressed a complex array of sectoral interests: areas of concern for marine life, regional seas, biodiversity, and academic disciplines as well as stakeholder interests. VECTORS aimed to explore, elucidate, and model links between all areas of interest, and then effectively communicate them to the relevant stakeholders. One of the goals was to create a synthesis with firm and detailed recommendations based upon all of the research outputs of VECTORS, targeted at the full spectrum of policymakers and stakeholders. As such VECTORS was totally focussed on The Ecosystem Approach *sensu stricto* in which humans are seen as an integral part of the ecosystem and the overall aim of marine management is to deliver ecosystem services for the benefit of society while at the same time maintaining, enhancing and protecting the natural capital of the marine environment.



Map of Europe showing the locations of the 38 VECTORS partners (from 16 countries) and the three regional seas; the North Sea, the Baltic Sea and the western Mediterranean which are used as case study areas for the project.



## Specific objectives of VECTORS

- » To collate understanding of the different current and potential future pressures and vectors of change in the marine environment
- » To better understand the mechanisms of changes in marine life and the role of human activity;
- » To determine the impacts of changes in marine life on ecosystems, their structure and functioning, the services they provide, as well as the economic and societal implications
- » To project the future changes and consequences of multi sectoral human activity in the marine environment under future possible scenarios of adaptation and mitigation
- » To synthesise the derived information into innovative predictive management tools and strategies targeted to different policy makers and other stakeholders

## The scientific objectives of VECTORS were highly interlinked:

- » To review understanding of the different current and potential future pressures and vectors of change in the marine environment

The intention of the early and rapid review was to provide the contextual scene for VECTORS and enable the project to build upon existing work. The review would: identify and prioritise the system drivers that create pressures of change which impact directly or indirectly on ecosystems and their biodiversity; provide a coherent understanding of the changing landscape of marine habitats and biodiversity; and assess the influence of these pressures on European marine and maritime economic sectors.

- » To elucidate mechanisms causing outbreaks of indigenous species and the spread of invasive species by transport or via other transfer vectors

VECTORS aimed to gain a better understanding of the ecological frames in which outbreaks are more likely to occur or invasions more likely to impact on native communities, with cascading effects on diversity and ecosystem functioning. Prerequisite to achieve this was the creation and compilation of databases of invasive alien species (IAS) and outbreak-forming species (OFS), inclusive of native species, which coupled environmental envelopes with taxon-specific, distributional and biological features in order to enable development of probability forecasting models of outbreak occurrence and long-term ecological consequences of invasions.

- » To distinguish between those mechanisms of changes in fish distribution and productivity that are caused by environmental and human-induced changes

VECTORS aimed firstly to identify and summarise the mechanisms via which the biomass generated by marine primary production changes on its passage upward through the trophic cascade/network. A second aim was to define how this flow of energy affects, and is in-turn affected by, the life cycles, motilities, and spatial distributions of species within the specific ecosystem. This included advanced integration of models to distinguish the mechanisms of changes in fish distribution and productivity and evaluate feedback mechanisms between altered availability of this biomass for harvesting, and exploitation patterns.

- » To develop a modelling framework aiming at predicting the impact of area-based restrictions on key sectors of activity

VECTORS aimed to analyse the determinants of human activities using qualitative approaches that consider all key sectors of activity and their interactions simultaneously, and quantitative approaches focussed on fishing activities and on how they might compete with other sectors operating in the same maritime domain. A dual qualitative/quantitative approach would be used to predict and model the response of different fishing activities to various area-based constraints including management and the competition for space resulting from other sectors' activities.

- » To quantify the impact of changes on ecosystem structure i.e. biodiversity and ecosystem functioning

VECTORS aimed to quantify the impact of the changes in marine life on ecosystem structure i.e. biodiversity and ecosystem functioning. This is vital for determining the capacity of coastal marine systems to sustainably provide goods and services to society. The effects of environmental changes on ecosystem status and dynamics vary considerably depending on the environmental context. In order to understand and predict the mechanisms responsible for altering biodiversity and ecosystem functioning and hence delivery of services, VECTORS sought to consider the complex interactions and interdependencies between the different physical, chemical, biological, anthropogenic components and the environment.





» To quantify the economic consequences of changes in marine ecosystems

Ecosystem services are an integration of many different ecological processes and ecosystem functions. The identification of the key components of ecosystems that provide the services, and the spatial and temporal scale at which they do so, facilitates the selection of suitable proxies or indicators of the services. VECTORS aimed to develop approaches to convert the diversity of available ecosystem data to a single value or benefit for each of the services, including aspects of spatial and temporal variation. VECTORS sought to analyse on-going and expected changes in ecosystem services and quantify the associated monetary and non-monetary impacts of changes including validation through a deliberative process of stakeholder public engagement. The estimated economic values of marine ecosystem goods and services would be transferred and incorporated into a general equilibrium model to address macro-economic impacts.

» To determine the effects of changes in ecosystem services and marine resources on the economic sectors which use them

VECTORS aimed to develop an integrated modelling framework underpinned by analysis of the impacts on different marine economic sectors and the interactions between them. The potential impacts on economic sectors depend on mitigation and adaptation strategies deployed by governments and economic sectors. VECTORS aimed to identify the possible strategies and assess their costs and benefits, risks and vulnerability towards determination of an optimal mix of future scenarios for mitigation and adaptation strategies. Whether these strategies are likely to be followed will depend on interactions between the different stakeholders and their organisations. Therefore, VECTORS aimed to analyse strategic interactions between different stakeholders from a game theoretical perspective focussing on how incentives for the different stakeholders will be affected by ecological changes and what implications these changes have for their cooperation.

» To develop, apply and test the generic findings of VECTORS research in regional seas case study areas

VECTORS sought to apply a case study approach addressing three regional sea areas (Baltic Sea, North Sea, Western Mediterranean) and building upon existing research. The objective was to facilitate coordinated data gathering including existing, & new (added value) data collection based on interdisciplinary research needs (e.g. ecosystem, social and economic) in locations with multiple sectors/pressures and specific areas of concern (investigate interactions). Knowledge gained would be synthesised for each regional sea concerning specific pressures and areas of concern including ecosystem, economic & societal impacts as well as future projections and implications for relevant stakeholders within the environmental, policy and economic spheres.

» To provide future projections of key environmental variables and changes in marine life in response to long-term climate change and key anthropogenic drivers

Different species exhibit different ecophysiological tolerances or preferences with regard to environmental variables. Looking at the current range of environmental conditions tolerated by a species, it is possible to predict future distribution if we know how the physical environment in an area will likely change in the future. VECTORS aimed to employ biogeochemical modelling approaches linked to 'down-scaled' Global Climate Models (GCMs) in each of the case-study areas to project future environmental variables. These could then be used in further modelling approaches to predict the future distribution and productivity of key marine organisms (commercial fish, invasive species, outbreaks etc.). VECTORS aimed to predict the potential 'habitability' of specific maritime regions for incoming or invasive species, the spread or re-distribution of key commercial species in response to future climate change and/or anthropogenic drivers and the likely social and economic consequences for industry, economies and society.





- » To describe and estimate quantitatively the possible future social and economic consequences implied by changes in EU Regional Seas marine ecosystems

Vectors aimed to conduct an integrated, quantitative, model-based analysis of the net economic impact of the on-going and predicted future anthropogenic and environmental pressures for major EU economic systems and their key economic sectors under different medium term scenarios. Changes in marine life and ecosystems could destabilize existing modes of cooperation between national and regional governments, commercial organisations, and other stakeholders and stakeholder organisations. The implications of possible future developments for existing modes of cooperation in marine policy would be investigated in the light of present and future pressures and of their economic consequences.

- » To develop and apply an integrative, cross-sectoral modelling framework that allows evaluation of the costs and trade-offs of maintaining economic activity in various sectors while protecting natural resources

Utilising the information on the present situation gained through the project, VECTORS sought to develop cross-sector model framework(s) by updating, improving & integrating existing models including application and parameterisation of the Atlantis model in the North Sea. These models would be implemented to investigate future scenarios for adaptation and mitigation considering the introduction of new technologies and structures, such as off-shore wind energy devices, new fishing strategies and new policy needs.

- » To use a synthesis of governance to produce recommendations to be included within a final synthesis of the VECTORS project targeted at policy makers and stakeholders

This would provide data and tools to relevant stakeholders within the environmental, policy and economic spheres and recommendations that will contribute to formulating feasible adaptive management strategies for the EU. The synthesis would elucidate clear linkages between science and policy. In cooperation with stakeholders VECTORS aimed to identify, review and evaluate current forms and mechanisms of marine governance including the integration of national and regional forms of marine governance into EU marine governance and vice versa and the opportunities and barriers for governance. Comprehensive tools would be developed to support effective and concerted implementation of marine management systems and in particular implementation of the IMO Convention on ballast water management at the EU level.

### *Integrative research approach*

The integrative research approach was emphasised from the beginning of the VECTORS project and throughout. It was achieved through strong interdependency between work packages and sub work packages that often addressed the different objectives jointly; through integrative workshops that, for example, jointly developed scenarios to be used by different work packages and by different disciplines; through a focus on ecosystem services, linking natural science and social science outcomes mediated by governance and social drivers as well as global change scenarios; through development of generic research understanding that was applied and tested in regional sea contexts; through identification of Researchers to act as 'Champions' of the different areas/sectors of interest to VECTORS (Outbreaks, Invasives, Distribution and productivity, Biodiversity and natural science, Economics, Governance and social science, Stakeholders: policy, Shipping, Energy, Fisheries, Conservation, Tourism, Science, Baltic Sea, North Sea, Western Mediterranean), the champions promoted and encouraged research and dissemination of research in their areas and ensured that a focus was maintained in VECTORS across all of the relevant facets of marine life change and its consequences.



# Description of the main results

VECTORS research was reported in a total of 31 deliverables (D) and has been summarised in a format aimed at policymakers and other stakeholders on the VECTORS website [www.marine-vectors.eu](http://www.marine-vectors.eu). The main results are described below under the title of the deliverable in which they are reported. However, this format does not indicate the interdependencies of the research undertaken across the different deliverables.

## D1.1 Review of regional seas vectors and drivers

The main aim of this early project review was to identify and disseminate the most up-to-date understanding of drivers that create pressures of change which could affect the areas of concern to VECTORS, i.e. invasive alien species, outbreak forming species, and changes in species distribution and productivity in the three European regional seas: the North Sea, the Baltic Sea and the Western Mediterranean Sea. The review provided the contextual scene for the subsequent research in the project and reduced redundancy of effort with respect to previous work and maximised opportunities to make future progress. The review was the first step towards identification, prioritisation and quantification of the direct and indirect pressures for change in the three European regional seas.

Information on the following drivers of change was summarised and synthesized (by three European regional seas): climate change and related impacts; ocean acidification; fisheries; pollution, discharges and hypoxia; maritime transport; energy demands and new technologies; introduction of new ballast water technologies and practices; changes in policy; and interactions between multiple users and sectors. Selected highlights include the following:

- » In addition to the primary drivers, a multitude of secondary drivers related to climate change were identified and their impact on ecosystem structure and functions summarised. Interactions of climate drivers with other drivers affecting marine ecosystems might be substantial and identification of their separate effects will be insufficient for the prediction of system behaviour. The study of interactive effects therefore becomes more critical.
- » The European fisheries are regionally very diverse ranging from highly industrialised pelagic fisheries (mostly in the Northern Europe) to small-scale artisanal fisheries throughout much of the Mediterranean. In addition to examining the spatial footprint of fishing activities, an overview of data sources on fishing pressure was provided.
- » Several pressures were investigated within the 'Land Based Pollution' driver. These were: hypoxia, turbidity, eutrophication, redox potential discontinuity, biological and chemical contamination. Impacts and ecological consequences of these pressures were characterised and quantified at sub-regional scales of the three regional seas.
- » Vessels operating in EU ports are currently increasing in size. While the North Sea hosts the three largest cargo ports in Europe (and will therefore be affected by the related pressures), the Mediterranean Sea is highly susceptible to ship-mediated bioinvasions. Assessment of environmental impacts of maritime transport is a challenging task, as multiple activities carried out in ports should also be taken into account.
- » Associated with increasing energy demand, the ambition of many EU governments to accelerate marine renewable energy developments will require more space at sea in future. The nature of exploitable renewable energy resources (wind and waves) differ across the regional seas and according to the environmental setting. Therefore spatially variable impacts on the structure and function of local marine ecosystems are to be expected. The commercial and environmental pressures to establish new resources must be appropriately balanced by environmental protection and monitoring practises.

- » An initial review of ballast water treatment systems, currently in use as well as those likely to be developed in the future, was provided together with preliminary information on their application on vessels, capacities and installation requirements. It is expected that development and implementation of these systems will proceed at an accelerated rate.
- » An overview of relevant governmental policies of importance for VECTORS at three levels (international, EU, regional) was presented, together with an analysis of the major themes in which VECTORS is covered and by which policy and also of the interlinkages between the regional sea case studies and policies.
- » Examples of multiple uses and their interactions, as well as existing and potentially arising conflicts in European regional seas were identified and described.

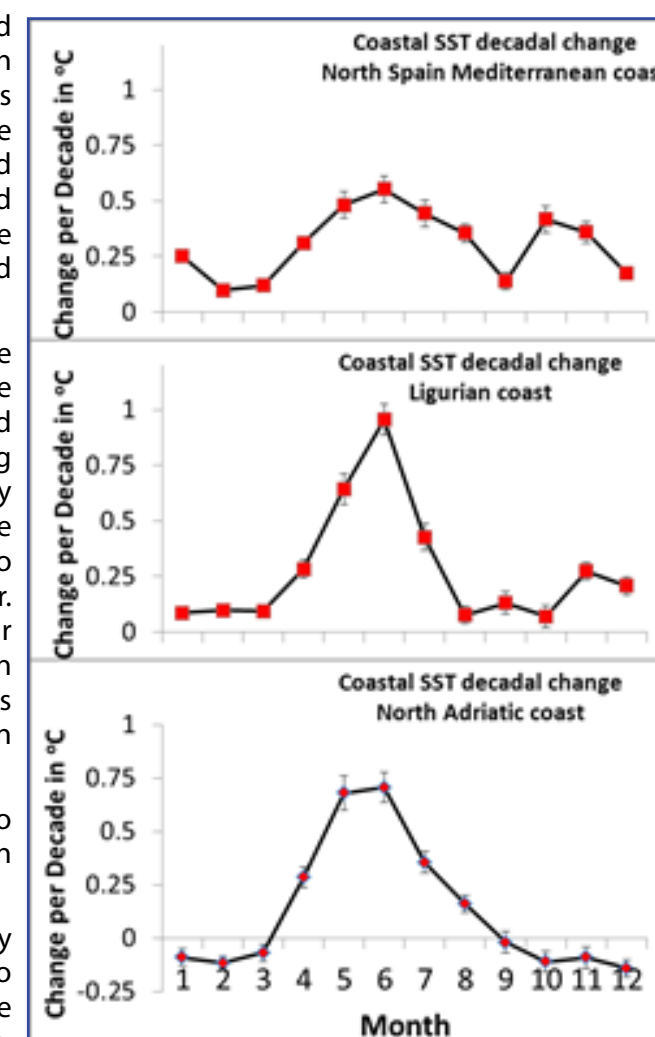
## D1.2 Direct and indirect pressures for change in European Regional Seas

Deliverable 1.1 served as a preliminary stage and informational platform for the completion of D1.2, which provided a coherent understanding of the current status of marine ecosystems. The purpose of D1.2 was to facilitate further assessment of the influence of the selected pressures on marine and maritime economic sectors and also to serve as a critical information source to project the future trajectories of these drivers, related pressures and consequences.

**Climate change.** The change in temperature within the North Sea in the late 1980s has established a new regime of ecosystem dynamics by modifying the strength and direction of many trophic interactions and favouring jellyfish, decapods and echinoderms. This strongly suggests that the North Sea ecosystem is vulnerable to variation in climatic conditions in general, and to anomalies in temperature and hydrodynamics in particular. Several processes within the North Sea food web appear to be triggered by temperature, and further increases in temperature may continue to disrupt the connectedness between species potentially leading to changes in community structures and possibly local extinctions

In the Baltic Sea, changes in temperature regime seem to be a common significant forcing factor for the population dynamics of most of the alien species.

The physical conditions of the Mediterranean are rapidly changing, and its biota is responding dramatically to these changes. Several phenomena co-occur at the species or community level: range shifts, mass mortalities, frequent species outbreaks (mostly gelatinous species) and intensified bioinvasions, all presumably related to climate shifts. These changes are causing a progressive



Change in SST per decade in three selected points in three regions in the western Mediterranean. Data generated from [coastalwarming.com](http://coastalwarming.com).



Examples of vectors of change – from drivers through impacts to policy responses.

Driver	Pressure/activity	State change	Impact on human welfare	Response
Increasing urbanisation, agriculture and industrialisation	Changes in temperature regimes and weather patterns (storminess)	Climate change and related impacts (natural and anthropogenic; effects on structure and functioning and on Ecosystem Services (ES))		Local adaptation, compensation; policy, economic & legal mechanisms
	Increased CO <sub>2</sub> and decreased pH	Ocean acidification	Reduced ecosystem services, ability for waste removal	Global agreements
	Diffuse and point source land-based pollution	Polluted components; Harmful Algal Bloom formation	Environmental and food quality reduction, reduced ES	Diffuse and point-source discharge controls
	Space removal	Loss of carrying capacity	Loss (& gain) of ecosystem services	Planning controls, Marine Spatial Planning
Demand for food	Capture fisheries	Changes to local populations, spawning sustainability, by-catch and habitat damage	Stock viability, ecosystem services reduction	Economic and legal instruments
Maritime transport (demand for movement of goods, etc)	Aquaculture	Changes to local ecology	Ecosystem services (+ and -)	Introduction of new ballast water technologies and practices
Energy demands	NIS (non-indigenous species) introduction, infrastructure demands, pollution, dredging	Community change, habitat alteration	Pest introduction, invasive and nuisance species; effects on ecosystem services	
	Infrastructure demands	Habitat loss and gain, energy/hydrodynamic change	Effects on ecosystem services (+ and -)	Marine spatial planning, economic and legislative constraints
Tourism & recreation demands		Loss of natural habitats, reduction in resilience		Planning controls, coastal spatial planning
Total societal demands	Interactions between multiple users & sectors	Cumulative effects on natural structure and functioning	Effects on ecosystem services	Changes in policy

Examples of vectors of change – from drivers through impacts to policy responses (Elliott, 2014).

homogenization of the marine biota across regions in the Mediterranean. Concrete information on changes in ecosystem functions is however mostly lacking. A shift from a diatom-dominated ecosystem to a non-siliceous one may involve the whole Mediterranean Sea and have consequences for fishery and tourism activities. Over the past two decades an average of about 10 new alien species to the Mediterranean have been recorded per year with a total of 573 alien marine metazoan species recorded in 2009.

**Ocean Acidification.** There is evidence that the oceans of interest in VECTORS are indeed getting more acidic, although the response of organisms varies greatly. Currently there is insufficient evidence to determine the impacts of ocean acidification on the three areas of concern for VECTORS. However, it seems reasonable to hypothesise that ocean acidification will facilitate the translocation of alien species, increase the likelihood of species outbreaks (such as Harmful Algal Blooms) and significantly alter community composition and productivity.

**Fisheries.** Fishery and aquaculture products play a significant role in human diet, both in Europe and worldwide, as a source of protein-rich healthy food. Therefore, fishing is typically one of the most widespread pressures in the marine environment and a major 'driver' or 'vector' of change in marine ecosystems. Undoubtedly overfishing has caused the decline of many commercial fish stocks. Marine species have been deliberately introduced to European Waters in order to enhance fishing opportunities. Fishing alters the abundance and size/age structure of target populations and could theoretically have secondary effects on the wider food-web. Jellyfish numbers have increased and this has been ascribed to both climate change but also overfishing. However, the effects of fisheries and fishing on changes in species distribution and productivity are difficult to disentangle from the effects of climate change.

**Land-Based Pollution.** Water quality has improved in most areas of Europe but land-based pollution is a complex phenomenon that is common to most European seas. It involves a number of often inter-related pressures. Eutrophication causes algae blooms, including harmful blooms of both toxic and/or nuisance species, and affects regulation by grazers. Hypoxia affects the behaviour, distribution and productivity of fish either directly, through mass mortality or indirectly via loss of suitable habitat. It may also favour organisms known to tolerate lower dissolved oxygen concentrations in seawater such as jellyfish. Turbidity is increased by algae blooms and can affect prey/predator behaviour in fish as well as mating habits. Shadow effects can alter habitats of macroalgae and vascular plants. Changes in redox potential discontinuity depth, which results from hypoxia and the release of hydrogen sulphide in sediments, can have marked negative impacts on bottom fauna. Subsequent reoxygenation may favour opportunistic species. Chemical contamination can favour invading species that are less sensitive to contaminants.

**Maritime Transport.** Maritime transport is crucial for economic development but several environmental impacts are associated with this economic activity. The transfer of harmful aquatic organisms by ballast water and biofouling, gas emissions, oil pollution, sludge, sewage, garbage, transport of dangerous goods, antifouling coatings and underwater noise are all associated with maritime transport activity.

The United Nations recognised the transfer of harmful aquatic organisms and pathogens across natural barriers as one of the four greatest pressures to the world's oceans and seas, causing global environmental changes, and posing a threat to human health, property and resources. Prime vectors for global transfer are vessels' ballast water and bio-fouling.

**Energy demands and new technologies.** The greatest potential for offshore renewable energies in the North Sea, Baltic Sea and Western Mediterranean lies in wind energy. In addition to offshore wind, tidal and wave powered generation has particular potential in the dynamic coasts and seas of the Northern reaches of Scotland. Ocean currents may also provide enough energy for power plants on the north-west and south-west coast of Sardinia and the Sicily Channel. There is also potential for solar energy in the Western Mediterranean. The increasing development of renewable energy will have multiple social benefits including the reduction of global CO<sub>2</sub> emissions, the improvement of regional energy security and the creation of new economic/employment opportunities.



In the Baltic Sea conventional energy production is relevant because of the coastal location of generation sites. Nevertheless, marine energy developments will claim more space at sea which has the added complexity of sharing requirements with other sectors such as fisheries, transport, aquaculture and leisure use. Provision of solid platforms will not change the balance of species occurrence and dispersal, as the seabed is already scattered with ship wrecks. Productivity in the vicinity of extensive wind farms may be impacted, as such installations may cause eddy patterns influencing planktonic production and also modify the wind patterns downwind which can affect the mixing depth of surface waters. The North Sea is composed of soft sediment and has an anthropologically heavily disturbed sea bed (years of trawling) making benthic fauna of the North Sea not especially vulnerable to industrial energy installations. In the Western Mediterranean area there are concerns about endemic species of seagrass, which are very sensitive to turbidity and therefore to marine excavation, and about the development of wind farms along migratory bird routes.

**Ballast Water Treatment Systems (BWTS).** Ballast water treatment systems address ballast water as a driver in alien species introductions. Almost 100 BWTS are currently in use. Different water treatment technologies are used, mostly in combination, and applied in different stages of the ballasting process. A pre-treatment stage excludes solid material and bigger organisms; a treatment stage involves either chemical or physical processes; and a residual control stage is employed to neutralise any active substances used in the treatment stage. Significantly for EU industry in this sector, a worldwide market of close to 70,000 vessels will need to be equipped with such systems.

**Tourism.** The overall impact of NIS on tourism is not properly documented and may only be estimated. An important negative impact on tourism can be caused by blue green algae blooms which change the aesthetic and recreational values of beaches and coastal zones. Some species in this group also produce toxins which could affect humans. However, so far these algae blooms have not had significant impacts on tourism in Europe. Three examples of non-indigenous species having an effect on tourism are *Crassostrea gigas*, *Dreissena polymorpha* and *Eriocheir sinensis*. The recurrent massive jellyfish outbreaks that have appeared along the shores of the Mediterranean have been amply documented as causing health hazards and costly damages to tourism.



Algal Bloom, Miknik | Dreamstime.com

**Policy.** There are two key policies that deal specifically with VECTORS areas of concern: the Ballast Water Management Convention covering invasive and alien species and the Common Fisheries Policy (CFP) addressing the changes in distribution and productivity of species. Outbreaks of species are not exclusively dealt with by any EU regulation or international regulation, nevertheless both MSFD and Natura 2000 deal with the possible causes of outbreaks, for example eutrophication.

The Western Mediterranean is faced with the need for integration of different policies and the ecosystem approach in the Barcelona Convention; the North Sea has a clear conservation and environmental focus while at the same time being a relevant area for the CFP; and in the Baltic the Baltic Sea Action Plan stresses the need to coordinate and harmonise the work within the HELCOM and also with European and other international policies.

The main drivers covered by these policies are transport, discharges, fish exploitation and environmental change, with many of them covered in parallel by more than one policy (such as the MSFD and the CFP). Therefore the VECTORS main topics can be addressed by the existing regulations, and it can be argued that no real gap exists in the EU regulation, notwithstanding the clear benefits from further coordination of the current policies involved.

## Interactions between multiple users and sectors

The main uses in the sea-areas addressed within the scope of VECTORS include fisheries, oil/gas extraction, maritime passenger and goods transport, offshore wind farms, cables and pipelines, defence, biodiversity conservation, sand and gravel extraction, coastal infrastructures, as well as tourism and leisure uses. The nature of interactions between drivers can be considered neutral, additive, synergistic and interfering. The consequences of most interactions will depend on local context and thus the nature, scale and dynamics of the habitat must also be considered. This is conceptually moving towards “the ecosystem approach”. Such context-dependant interactions represent a particular difficulty in terms of transferring scientific knowledge into policy mechanisms. Examples of successful inter-sectoral collaboration and/or transnational co-operation are identified in the field of Marine Spatial Planning and existing marine governance structures. Difficulties in modelling the results of multi-vector effects, as well as the degree to which they interact, are challenging for the production of mathematical models (dynamic models).

## Scenarios used in VECTORS (no associated deliverable)

Drawing from the D1.1 and D1.2 reviews along with a review of existing scenarios and a focussed interdisciplinary workshop, VECTORS developed its own scenarios for application throughout the project in models projecting future changes and consequences of change. Making projections far into the future will always be a highly uncertain exercise, given that we do not know how human drivers will develop and evolve over time. There are an almost infinite number of possibilities and permutations and hence a common approach to bracket the future into coherent scenario storylines was adopted. Two scenarios for the near future (40-50 years) were developed representing opposing socioeconomic environments and mitigation strategies to illustrate the range of response of the system:

Global Community Scenario: International co-operation towards global sustainability

- » Based on the IPCC SRES “B1” Global Sustainability scenario, characterised by low CO2 emissions and a focus on global solutions to environmental problems.
- » People aspire to high levels of welfare and a healthy environment, the best way to achieve these aims is through international co-operation.
- » Sustainability is seen from a global viewpoint, including: maintaining biodiversity, protecting global commons and providing fair access to environmental resources.
- » Policies are co-ordinated at the European Union and international level. This is a high taxation scenario.
- » Major investment in offshore renewable energy projects
- » Internationally agreed control measures reduce the amount of pollution released into the marine environment
- » The health of the oceans across the world improves, although it is necessary to sacrifice some local areas for development.
- » National Responsibility Scenario: People aspire to personal independence and material wealth but within a national cultural identity
- » Based on the IPCC SRES “A2” National Enterprise scenario, characterised by high CO2 emissions and a focus on national self-sufficiency.
- » The balance of opinion favours increased national isolation and independence in economic, foreign and defence policy.
- » Long-term economic growth is limited by government policies, which protect important national industries.
- » By 2020, marine ecosystems come under greater pressure than at present.
- » Efforts to reduce the effects of human activity are abandoned where they conflict with issues of national self-sufficiency.
- » Large-scale, environmentally damaging projects such as tidal barrages and wide-scale oil exploration develop.
- » Governments fail to deal with global problems.



### D2.1.1 Repository tissue/DNA bank for outbreak forming species and invasive alien species (OFS/IAS)

A tissue/DNA biorepository that will provide baseline material has been constructed for use by the VECTORS and beyond-VECTORS scientific communities investigating European marine biodiversity. It will be/has been used for: validation of morphological identifications; assessment of genetic connectivity between populations; reconstruction of temporal dynamics and spatial pathways of outbreaks / invasions; identification of donor regions and vectors of introduction.

### D2.1.2 Mechanisms of change in alien and native species outbreaks

VECTORS has delivered new information to:

- Document the distribution of invasive alien species (IAS) and outbreak forming species (OFS);
- Determine the stochastic and deterministic drivers of proliferations and ecophysiological features boosting regime shifts of marine communities;
- Discriminate sources and vectors of bioinvasions;
- Foresee consequences of bioinvasions in terms of impact on ecosystem functioning and services.

Outcomes include AquaNIS which represents the most updated database resource available to scientists, coastal managers, stakeholders, and policymakers dealing with aquatic IAS in European seas. Novel data have been produced on OFS/IAS ecophysiology, behaviour, reproductive patterns, species interactions, ecological impacts, species growth rates, habitat susceptibility and drivers of invasions.

This new information from VECTORS has wide implications going far beyond the various study species and geographical areas, representing a model integrative approach towards a better understanding of the mechanisms of bioinvasions. Key findings can be summarised as follows:

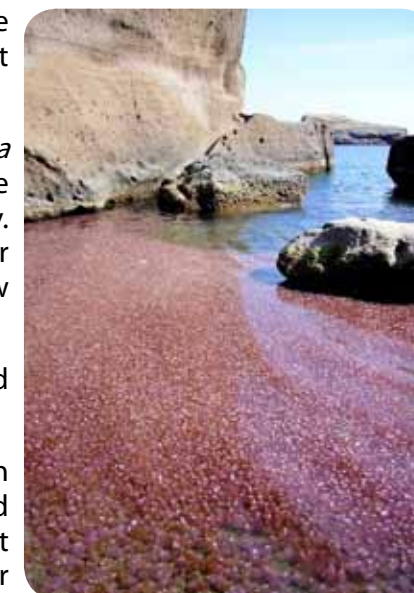
- » Large shifts in environmental abiotic parameters do not have uniform consequences on IAS and OFS biota, but biotic interactions play a key role in modifying local communities as a result of bioinvasions;
- » Climate-driven warming is expected to exacerbate the potential trophodynamic impacts of invaders;
- » Depending on whether thermal windows are exceeded at a single-species level, the productivity of endemic jellyfish species in the North Sea will not inevitably increase with sea temperatures;
- » In the eastern Mediterranean Sea, water temperature provides a mechanistic explanation for the replacement of indigenous species by thermophilic invaders, similar future effects in the western Mediterranean can be anticipated;
- » Return time of extreme jellyfish outbreaks in the Mediterranean Sea has been estimated as approximately 6.5 years;
- » Jellyfish outbreaks should not increase in the Mediterranean region simply as a consequence of environmental fluctuations. Extreme outbreak events are likely to occur in the near future at sites in the proximities of marine canyons. Cross-shore advection by geostrophic flow represents an important aggregating force



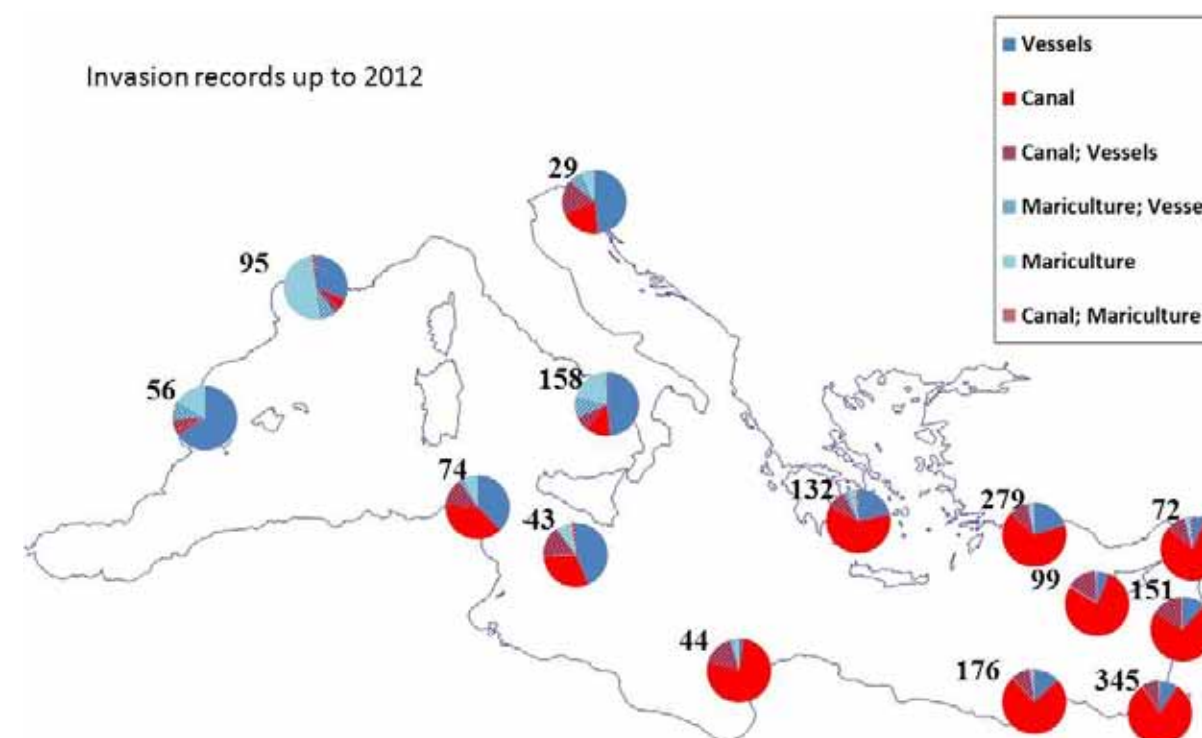
*Pelagia benovici*, a new species discovered in the Gulf of Venice by means of citizen science Piraino, Aglieri, Scorrano, Boero 2014.

of jellyfish. The ability to anticipate these extreme events in the future will require a better understanding of how environmental drivers affect demographic and population processes in jellyfish species;

- » Substantial insights on a key jellyfish species in European Seas, *Pelagia noctiluca*, have been achieved in terms of ecophysiology, reproductive potential, trophic interactions, and population genetic connectivity. An Individual-Based Growth Model (the first bioenergetic model ever developed for a jellyfish species) has been developed, providing a new tool to predict the ecological impact of *P. noctiluca* outbreaks;
- » New species of conspicuous alien jellyfish have been identified and described for the first time in European seas;
- » Risk of species translocations by shipping, aquaculture, sea food trade in European seas are still high, requiring reinforcement of surveillance and monitoring tools for prevention of new alien introductions; movement and marketing of live trade species should adhere to strict controls similar to those proposed for other pathways in order to prevent unintentional non- indigenous species introduction.
- » The recent enlargement (2010) of the Suez Canal is revealed to be critical for maximizing invasion success of Erythraean biota in the Mediterranean Sea; implications of future increases of the Canal's depth or width are manifest. The many recent records and rapid spread of several invasive aliens are documenting a Mediterranean Sea climate change signature.



Jellyfish bloom on Ventotene Island (Alessandro Montemaggiore)



Records of multicellular alien species and main drivers of invasions in the Mediterranean Sea.



### D2.2.1 A model for marine primary production

This deliverable describes a generic methodology for calculating new production, total primary production and f-ratios. The methodology has been tested and compared to new runs of existing numerical models for the years 2003 to 2008 in the North Sea region. All underlying data, model outputs and software tools for aggregation, comparison and visualization of the results are available on the VECTORS repository at Deltares, the Netherlands.

### D2.2.2 Predictive fish distribution and migration models

Five, broad categories of approaches used to model changes in the distribution and productivity of fish and other living marine resources were reviewed and compared:

1. Statistical techniques used to analyse temporal (time only) changes in field data,
2. Statistical models which can describe both temporal and spatial changes in field data,
3. Physiological-based models that merge ocean physics and the biology of single and/or all life stages,
4. Spatially-explicit food web models, and
5. End-to-end models that combine models of water physics, habitat biogeochemistry, food web interactions, and human pressures such as fishing fleet dynamics.

These broad categories differ in their ability to assess the effects of interactions between key pressures affecting living marine resources including i) climate-driven changes in temperature regimes and acidification combined with ii) reductions in water quality due to eutrophication, and/or iii) the introduction of alien invasive species, and/or iv) reductions in biomass of stocks / populations due to commercial exploitation (fisheries).

Exploring field data using statistical approaches is an important first step in detecting patterns and strengths of associations between physical and biological components of ecosystems. These analyses can help generate hypotheses regarding processes acting to generate complex patterns observed in field time series data. These complex patterns include large-scale, ecosystem reorganizations such as regime shifts (from one stable state to another) and complex predator-prey dynamics such as trophic cascades (reciprocal shifts in adjacent trophic levels).

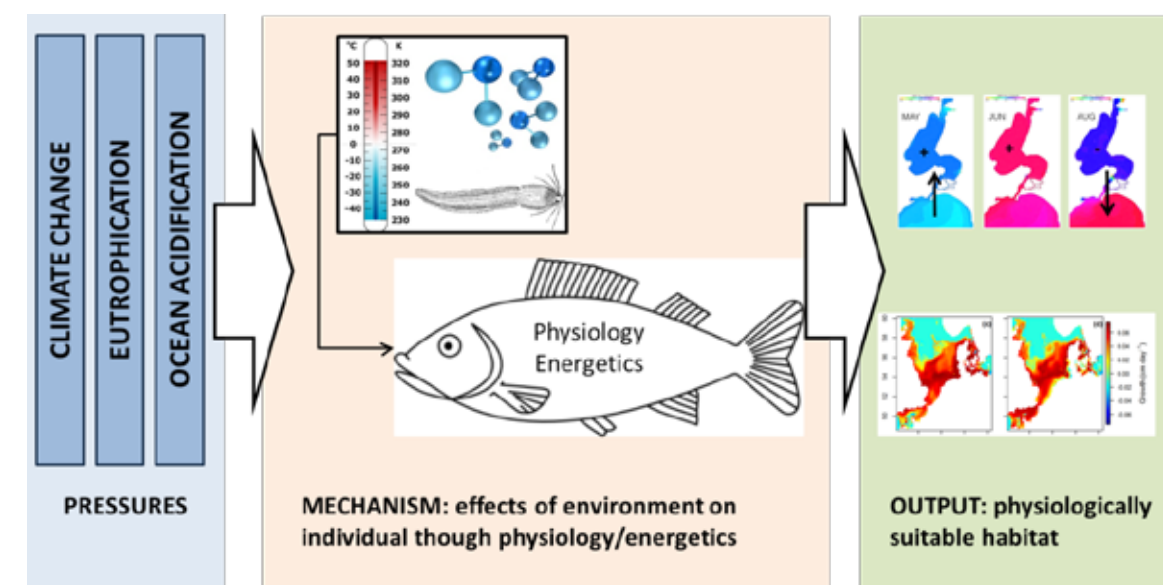
A consensus opinion emerging from the review of mechanistic models is that advancement in predictive capacity requires adding a biological and physical mechanism into models to provide a cause-and-effect understanding of the impacts of multiple pressures. Continuing to add key physiological mechanisms that shape individual behaviour and species life history strategies is a priority as is increasing the realism of food web interactions occurring at different spatial scales.

Many of the models reviewed are fairly mature (having been used for many years to decades) and a coupled model approach is now recommended that can thoroughly examine key processes. These include those processes emerging from changes in physical controls on the availability of prey or suitable (physical) habitat characteristics for fish (bottom-up processes) or changes in the number (and/or efficiency of prey capture) of predators (top-down processes). An important consideration driving the development of full life cycle models is that different processes can act on different life stages of key species, their predators and their prey. Models that only examine single life stages may not capture the relevant drivers of changes in populations. Finally, End-to-end models (e.g. physics to fish to human pressures such as fisheries) offer one of the few opportunities to assess how multiple pressures may interact to cause changes in living marine resources. At the present time, these models are most useful for strategic decisions based upon relative differences (cost and trade-offs) arising from different spatial management actions but are less suited for quantitative (absolute) projections.

### D2.2.3 Mechanisms of change in species distribution and productivity

VECTORS has improved our understanding of the generic mechanisms of changes in species distribution and productivity (including exploited species). The research focussed on combined effects of broad scale and local drivers of change and combined effects of local drivers considered likely to co-occur, particularly in the case study areas. New information has been delivered to:

- » Identify the changes in pathways and/or rates of turnover which impact the flow of primary production on its passage up the subsequent trophic cascade/network;
  - » Determine how this flow of energy affects, and is in-turn affected by, the life cycles, motilities, and spatial distributions of species within the ecosystem;
  - » Distinguish those mechanisms of changes in fish distribution and productivity that are caused by environmental and human-induced changes including evaluation of feedback mechanisms between altered availability of this biomass for harvesting, and exploitation patterns; and
  - » Advance integration of models to assess the feedback effects of changes in productivity on distributions.
- Findings from the research include:
- » Identification of variables which are key in driving species distributions: temperature, salinity, oxygen, sediment type, currents, prey availability, predator-prey overlap;
  - » There are tolerance ranges and limits to specific variables (temperature, salinity, oxygen, pH) that are key in defining an organisms fundamental niche (suitable habitat);
  - » Connectivity between ontogenetically different habitats is key for the success of a population relying on different areas for different needs at different life-stages;
  - » Some mechanisms remain difficult to model such as: behaviour at the level of the individual, evolution of migration pathways and adaptations that may occur to new conditions experienced over time;
  - » Changes in productivity will feed directly into changes in species distribution and affect the energy flow within the system; and
  - » In order for more reliable future projections to be made a coupled modelling approach is necessary to incorporate multiple key processes.



Flow chart illustrating which of the VECTORS defined drivers are relevant for this mechanism of change in species distribution, the mechanisms by which the organism is affected and the type of output that can be obtained relevant to spatial distributions.



### D2.3.1 Mechanisms of change in human behaviour

VECTORS has improved understanding of the key processes driving the behaviour of human agents utilising a variety of EU maritime domains. Particular attention has been paid to the spatial interactions between fishing activities and other human uses (e.g. maritime traffic, offshore wind farms, aggregate extractions), but the behaviour of non-fishing sectors of activity has also been considered. Various quantitative and semi-qualitative approaches were pursued to gain better insight into behavioural drivers based on past data, and also to forecast how human agents would react if access was constrained by either management (e.g. Marine Protected Areas – MPA), or the installation of a new operator. Quantitative research consisted of analysing fishing decision-making processes based on existing data and then making forecasts building on scenarios, while qualitative research consisted of interviewing stakeholders from different sectors of activity to get their views on both their past and likely future behaviour.

Models developed, refined and applied in VECTORS indicated that traditions (reflected by past effort allocation) and economic opportunism are driving factors for effort allocation in both the Eastern Channel and the North Sea for the French, English and Dutch fleets investigated. Economics and tradition remain more important in driving effort allocation than spatial interactions/competition with other fishing fleets, maritime traffic, aggregate extraction, wind farms and closed areas. These model results were largely confirmed by interviews with stakeholders.

In the Eastern Channel maritime traffic adversely influenced English and Welsh scallop dredgers but spatial distribution of Dutch fly-shooters (demersal seine) did not appear to be substantially affected. Many, but not all, of the French fleets tended to avoid shipping lanes except when stock density was high. In both the Eastern Channel and German Bight maritime traffic has been a constraint for fishing activities, but is less so nowadays due to the decrease in the number of trawlers. In other regions (Dogger Bank, Gdansk Bay), maritime traffic did not appear to be an important issue to interviewed fishers.

At a broad spatial scale, over the whole Eastern Channel, aggregate extraction restricts English scallop dredgers. However at a more localized level (i.e. for each aggregate extraction site), and for a wider range of English and French fleets, the interactions between aggregate extraction and fishing activities are of a more complex nature. Some fleets were attracted to the vicinity of aggregate extraction sites.

Fishers' interviews indicated that wind farms were seen as a concern in the Eastern Channel, the German Bight and the Gdansk Bay, but less so in the Dogger Bank. Oil and gas platforms are already operating in the North Sea, and these are considered as an issue by some fishers operating in this region.



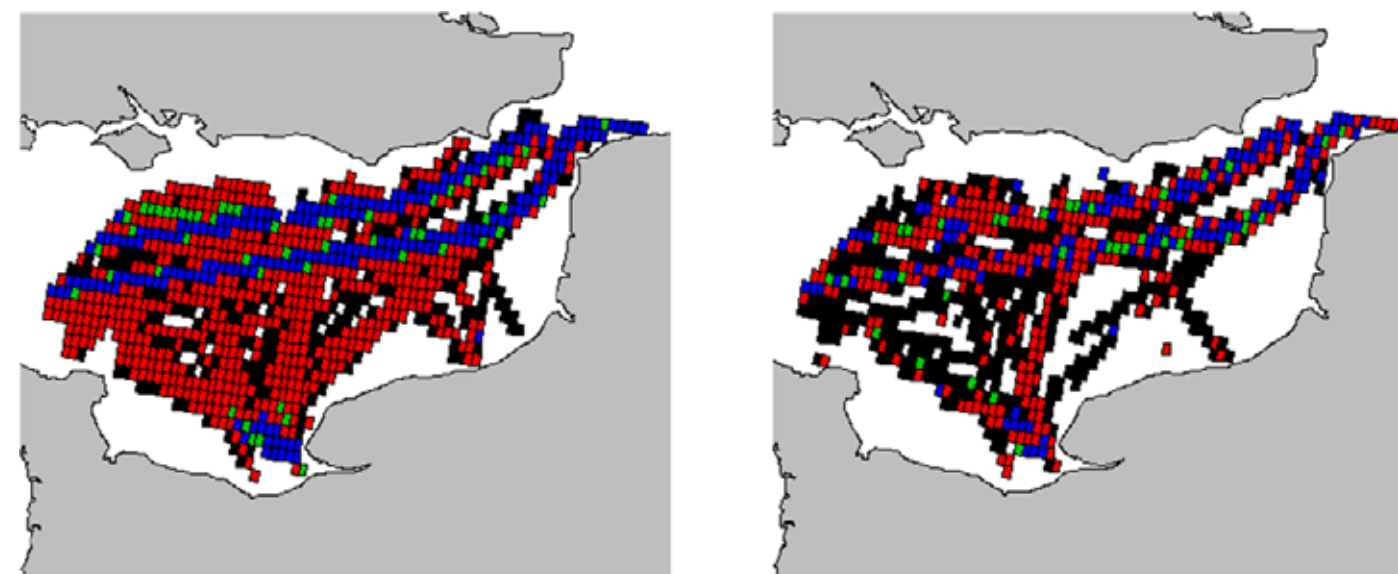
Dredging platform. Dreamstime

Competing stakeholders have found ways to work together for integrated spatial management or are learning to work together. Some stakeholders come together to push for similar aims and alliances can take place even between traditional "competitors." In the English Channel, groups in general seem to compromise and come together, despite differences. The conservationist mandate has been strengthened in recent years, but is being tempered by the UK government's vision for "clean, healthy, safe, productive, and biologically diverse oceans and seas;" consequently pragmatism and compromise is automatically built-in to the system. The UK has also formed statutory bodies whose role is to liaise with industry to help minimize impacts on the environment. In contrast, on the Dogger Bank and in the Gulf of Gdansk, conservationists and other groups appear less willing to compromise, making integrated management much more challenging. In the Dutch situation most consultations are with other federal agencies, major marine industry sectors, and public review of plan documents. However, Dutch respondents don't think they have any influence on these developments.

A range of forecast models with different structures were applied to predict the bio-economic impact on fishing fleets of (quota-induced) resource competition combined with discard restrictions and of area-based restrictions (inferred by other fleets, other sectors of activity, and/or closed areas) in the short- and the medium-term. These forecast models can be ranked by increased complexity, which also provides indications on how these should be understood and/or used by marine managers. Simple models provide short-term forecasts based on historical data only. They can be used by managers to quickly anticipate the stress fishers may experience in the short term as a result of the installation of a new plant overlapping with their fishing ground (e.g. oil rig, wind farm) or the enforcement of a new closed area. However, they cannot be used to predict the effects on fishing effort of spatial displacement or the knock-on pressure exerted on marine ecosystems (and on commercial species in particular). More complex models explicitly build in fleet dynamics in the form of effort allocation but do not build in the dynamics of fish populations. These can be used to evaluate the impact of catch quotas combined with a discard ban or area-based restrictions on fishing effort allocation one year ahead. The most complex of the models investigated account for the dynamics of fishing fleets, fish populations, and economics. They can be applied to evaluate the impact of area-based restrictions, in combination with conservation management measures, on the conservation and economic utilization of fisheries resources in support of marine planning at a fine resolution or to evaluate the impact of economic incentives and right-based management (e.g. Individual Transferable Quotas).



Fishing Boats. Dreamstime



Marine traffic intensity (13 October 2008, right panel and 11 of October 2008, left panel). Black, red green and blue squares represent 3\*3' square where Marine traffic intensity is less than respectively the first, second, third and last quartile of the observed marine traffic intensity during October 2008.



### D3.1.1 Online collated data on impacts of mechanisms of change on biodiversity, ecosystem functioning

To realise the full potential of existing data in a policy context and to provide an empirical basis for ecosystem models three carefully planned systematic reviews were undertaken using appropriate protocols. The reviews focussed on impacts on biodiversity and ecosystem functioning of IAS, OFS and changes in distribution and productivity with particular focus on case study regions. Each review addressed the impacts of the selected mechanisms on a range of components of biodiversity (benthos, fish, plankton, birds and mammals) and on measures of ecosystem functioning and analysed the applicability of findings across a range of scales and systems.

### D3.1.2 Synthesis of evidence for impacts of changes

Research has quantified the impact of changes in distribution and productivity of species and outbreaks of indigenous or invasive species on ecosystem structure i.e. biodiversity (species richness, identity and relative abundances and physico-chemical parameters) and ecosystem functioning. The three systematic review reports, produced in D3.1.1, provided quantitative syntheses of current knowledge of effects on biodiversity and ecosystem functioning of (a) outbreaks of macroalgae (b) invasive primary producers (with particular reference to intra- and inter-trophic effects) and (c) invasive ecosystem engineers. Surface-water Modelling Systems (SMS) indicated the relative importance of mortality due to fishing and predation for a number of commercial species and demonstrated the potential influence of outbreaks of predatory species. Key findings include:

- » Overall, macroalgal blooms caused reductions in the abundance of organisms and the number of species. They also caused increases in the gross primary productivity of benthic communities but did not have statistically significant effects on four other key measures of ecosystem structure and functioning. However, the effects differed from overall effects at the regional sea level, with several factors contributing to variation in the effects estimated by different studies. The algal taxon responsible for a bloom influenced its effects on community abundance and species richness, possibly because of differences in the complexity and cohesion of the algal mats that they produce. Blooms also had different effects on species richness in different habitats.
- » Work dealing with the causes and consequences of macroalgal blooms tends to emphasize their undesirable, negative effects on marine and estuarine assemblages. Although negative overall effects were found on community abundance and species richness, results revealed a more complex picture of the impacts of macroalgal blooms. This fuller view of the effects of blooms ought to be taken into account in decisions regarding the management of macroalgal blooms and their drivers. For example, concerns about the negative social and economic effects of macroalgal blooms are often focused on intertidal beaches. Removal of algae from beaches will increase their attractiveness, and reduce the risk of hydrogen sulfide poisoning. However, VECTORS results suggest it will have little effect on the abundance of beach fauna, and may even lead to slight reductions in species richness. Thus, if preserving biodiversity and abundance is an additional objective of bloom management, one may also wish to target rocky intertidal and subtidal soft sediment habitats where the effects of blooms are more severe.
- » In general, the introduction and spread of non-indigenous benthic macroalgae into the marine environment has a negative effect on native primary producer communities and species. This effect is greater than that experienced at higher trophic levels in native benthic ecosystems. The effects of non-indigenous seaweeds did not generally vary among areas characterized by a different degree of human impact. However, the effects on the abundance of consumer species and community diversity changed from clearly negative in relatively pristine areas to neutral or slightly positive in areas heavily impacted by human activities. A negative impact of non-indigenous seaweeds on native primary producers may result in the lessening of important ecosystem services, such as nutrient cycling, carbon storage, mitigation of coastal erosion through the dampening of wave action, reduced amenity and recreational value of coastal areas.

- » Although invasive ecosystem engineers have great potential to strongly affect native community structure, biodiversity and ecosystem functions, VECTORS analysis revealed highly diverse trends in the overall response of individual species, communities and their function to the presence of invasive ecosystem engineers. The overall (averaged) effect on individual species was small but negative. At the community level, many studies showed a strong effect of the invader on different community attributes, but the overall summary effect was small and non-significant. In contrast, there was an overall strong effect for most ecosystem functions considered. Species diversity, richness and evenness were strongly negatively affected in the Mediterranean but showed no trends in other regions. VECTORS has developed a conceptual framework of the different pathways that may lead to impact on ecosystem function and biological communities by invasive engineer plants and epibenthic sessile invertebrates.
- » The importance of predation relative to fishing mortality has been increasing in recent years due to a successful reduction in fishing mortality for many stocks in the North Sea. The percentage of natural mortality in total mortality is a useful food web indicator disentangling natural and anthropogenic pressures on fish stocks.
- » Outbreaks of indigenous predators like grey gurnard can have a serious impact on the stock dynamics of commercially important fish species such as cod or whiting.

### D3.1.3 Novel experimental evidence for impacts of biodiversity on ecosystem functioning

Five experimental case studies were completed in the VECTORS regional seas to test effects of selected invasive species on native ecosystems and, in some cases, to examine the extent to which those effects vary with the density of invaders and the environmental context.

Key findings include:

- » Invasive algae in the Mediterranean have a greater impact on native assemblages in pristine areas than in areas affected by human activities. It is therefore recommended that management actions focus on preventing the spread of the species to pristine areas.
- » In the Gulf of Oristano, Sardinia, the flow of carbon from the first to the second trophic levels of the benthic food web is at risk from the invasion of the Asian mussel (*Arcuatula sehnousia*) with potential consequences for the entire coastal food web.
- » Chinese mitten crabs (*Eriocheir sinensis*) maintain their bioturbatory activity at low temperatures, which may enable them to expand further northwards than previously considered likely. They burrow more deeply than the average depth of other species in the region and may cause changes in erosion, turbidity, nutrient release and siltation rates with possible impacts on fish spawning grounds.
- » The mechanism by which the invasive amphipod *Gammarus tigrinus* replaces native amphipods in the Baltic is related to high fecundity and strong predation pressure of invasive adults on native juveniles.
- » Invasive mud crabs (*Rhithropanopeus harrisi*) in the Baltic reduce biomass of all bivalve and gastropod species regardless of sediment or vegetation type. The arrival of crabs in the Baltic marks a significant transition for the system.
- » Although the invasive and predatory cladoceran *Cercopagis pengoi* has significant potential for influencing Baltic pelagic zooplankton community structure and function it does not appear to be causing a major shift of the invaded ecosystems into a new regime. Its predation impact on the copepod *nauplii*, which are important food for small herring larvae, might be substantial, but is likely to be of relatively limited importance for the larval fish as it occurs substantially later than the first-feeding herring larvae appear.



### D3.2.1 Impacts of change on ecosystem services and their values

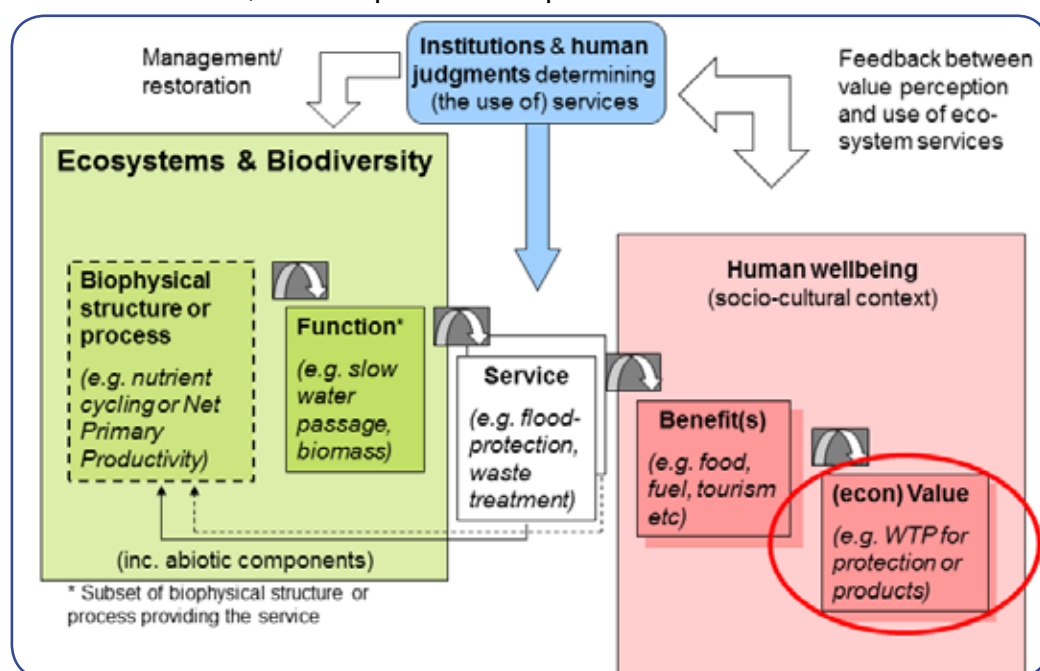
Through the assessment of ecosystem services VECTORS has helped to improve our understanding of how environmental and man-made factors and changes in marine life impact marine ecosystems and what the consequences are. The outputs are timely because there is a growing demand for the incorporation of ecosystem service assessments into the marine planning process and an urgent need for examples of how this may be achieved, especially for offshore locations. VECTORS has:

- » Reviewed, developed and refined ecological indicators for quantifying the ecosystem goods and services provided by marine ecosystems;
- » Analysed (ongoing and expected) changes in ecosystem services as a result of invasions and outbreaks, changes in distributions and productivity and changes in ecosystem structure and functioning;
- » Quantified some of the monetary and non-monetary effects of changes in ecosystem goods and services;
- » Validated the findings of ecosystem valuation through a deliberative process of stakeholder engagement;
- » Examined the positive and negative impacts of jellyfish outbreaks to inform management decisions.

An ecosystem service classification was developed and tailored to the Dogger Bank and the Gulf of Gdansk. Indicators were then developed for each ecosystem service, the processes and functions that generate them and the benefits they contribute to. For both the Dogger Bank and the Gulf of Gdansk, these indicators were assessed and quantified, where data allowed. Changes in these indicators from the present day were explored through two different scenarios used in VECTORS (the IPCC 2000 scenarios A2 National Enterprise and B1 Global Community). In a third case study, the Catalan Coast, only the service of food provision was explored, but the findings provide a detailed analysis of fish stock viability under the two scenarios.

Data limitations restricted the possibilities for ecosystem service valuation based on secondary data. Discrete choice experiments were undertaken to collect new valuation data in three locations: the Dogger Bank, the Gulf of Gdansk and the Catalan Coast. The Dogger Bank study focused on the willingness-to-pay (WTP) for changes to species diversity; protection of porpoises, seals and seabirds; and the level of spread of invasive species. The Gulf of Gdansk study explored WTP for ecosystem services delivered by seagrass meadows (biological control, recreational importance and waste treatment and assimilation), while the Catalan Coast study examined the impact of jellyfish outbreaks on the cultural ecosystem service of leisure and recreation. A contingent behaviour study was also conducted for the Catalan Coast, which explored the impact of offshore wind farm construction on coastal recreation. A positive WTP was expressed for all ecosystem services.

For the Dogger Bank and the Gulf of Gdansk, deliberative assessments were also carried out to complement the discrete choice experiments. In both cases conservation and the protection of the environment were recognized as important. However, the need for environmental protection to be in balance with economic uses was also highlighted.



The links between the environment and leisure, recreation and tourism were explored in more detail. Using a macro-level approach the impact of ecosystem quality on inbound coastal tourism in the countries bordering the Baltic Sea, Western Mediterranean and North Sea was explored. Deterioration in ecosystem quality has an unambiguously negative effect on inbound tourism, supporting the need for ecosystem protection.

Additional surveys undertaken in Italy, Spain and Malta examined the impact of jellyfish outbreaks on beach-goers. The threat of a jellyfish outbreak does not cause the majority of respondents to change the location of their beach visit. Most would return to the same beach, although they would not enter the water. Respondents were interested in receiving a daily jellyfish alert by SMS and having access to more information about beaches where anti-jellyfish nets are installed. Despite this, most would not be willing to pay a €12 fee to ensure their installation.

Assessing marine ecosystem services remains challenging. Lack of ecological data and knowledge limited all aspects of the assessment from the identification and assessment of indicators to the macro-level assessments. While substantial bodies of information exist for the case study sites, much of what has been collected does not fit within the ecosystem service concept and consequently does not align with the ecosystem service indicators selected. This affected the selection of attributes for the choice experiments as well as the ability of members of the public to prioritise issues during the deliberative workshops. Ecological content validity is also a key concern when translating ecological evidence into readily understandable material for the general public. Better ways of communicating such complex information are required. To help overcome this, full assessments require interdisciplinary teams. This also helps to ensure that the outputs of the different ecosystem service assessment and valuation activities are relevant to environmental management.

### D3.2.2 World Jellyfish Patents (WJP) Database

The marine environment has been recognized as a rich source of bioactive metabolites with various biological and pharmacological activities. The chemical complexity and biological diversity of the marine-derived compounds is enormous, so that bioprospecting of marine organisms today represents a major tool for the discovery of new therapeutic agents and drug candidates.

On a global scale, high-density outbreaks of jellyfish populations in coastal marine ecosystems provide a large amount of jellyfish biomass that could be a valuable source of bioactive compounds beneficial for humans, including bioactive peptides, collagen and gelatine, oligosaccharides, fatty acids, enzymes, calcium, water-soluble minerals, and biopolymers. Various biological activities have been identified, including anticancer and antioxidant activity, that make jellyfish a potentially valuable material for food, cosmetic, and biomedical industries. VECTORS has created the World Jellyfish Patents (WJP) database which collates available information on international patents on jellyfish utilization in different fields, such as biological applications, cooking treatments and recipes, pharmacological and cosmetic uses.



### D3.3.1 Impact of ecological changes on economic results of different marine sectors

VECTORS has increased understanding of the economic implications of ecosystem changes and multiple human activities. VECTORS has: analysed the impact of ecological changes on the economic results of the different marine sectors; identified and analysed key interactions between multiple uses and sectors; analysed different strategies for mitigation and adaptation and; analysed the incentives for international, interregional and intersectoral cooperation in managing the marine environment. Much of the analysis was undertaken in relation to the VECTORS scenarios A2 (National Responsibility) and B1 (Global Community).

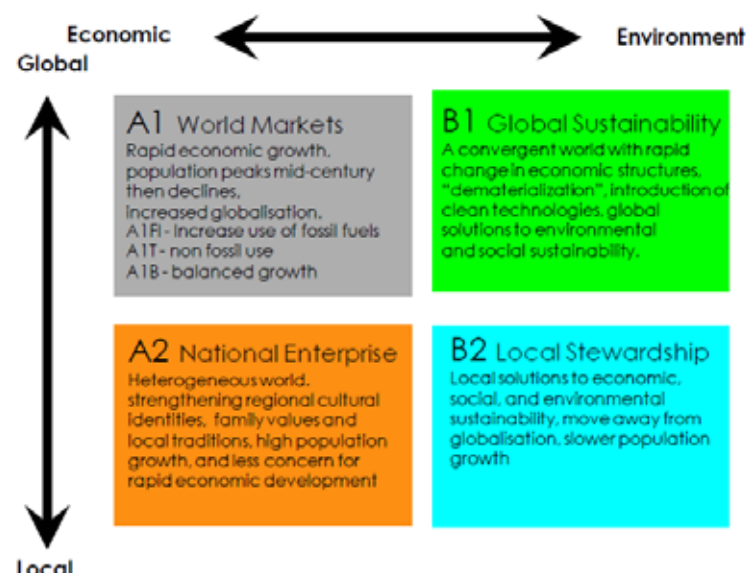
Key findings include:

- » In the North Sea flatfish and shrimp fisheries, the combination of changes in distribution of fish stocks, area closures and higher fish prices in scenario A2 would have a positive effect on net present value (NPV) of net profit (+8%) between 2010 and 2050. In scenario B1 the increase in fish prices is lower and cannot compensate for the negative effects of shifting fish stocks, area closures and rising fuel prices resulting in a negative effect on NPV of net profit (-14%).
- » The introduction of individual tradable quota (ITQs) in the North sea flatfish fishery would improve the efficiency of the fishery slightly (0.35-1%), resulting in a higher NPV of Gross Value Added (GVA) in both scenarios.
- » A Northward shift of the North Sea saithe stock would lead to lower profits for the saithe fleet in both scenarios. The difference in profits between scenarios is due to differences in Spawning Stock Biomass (SSB), fishing effort and fuel prices. The allocation of fishing effort in saithe fishery follows the migration patterns of the stock but the relationship becomes less strong when fuel prices increase. This causes fleets to stay closer to the ports and leads to a concentration of fishing effort in a smaller area.
- » In the Western Mediterranean immediate strong action to reduce fishing effort to the level corresponding to fishing mortality at maximum sustainable yield (Fmsy) is the best strategy in the long term to attain both viable fish stocks and viable fishing fleets.
- » For Western Mediterranean bottom trawlers and purse seiners, economic results for the fishing fleets are much better in scenario B1 than in A2, partly because of stricter fishing policy and partly because of lower fuel prices. Climate change is not expected to have important effects on the economic results of these fisheries over the scenario period.

» There are indications that non-indigenous species can have a higher impact on aspects of bio-fouling on maritime transport that can affect fuel consumption than indigenous species in the three European seas studied. This is due to common biological traits of non-indigenous species such as higher average growth, higher salinity tolerance, resistance to pollutants or antifouling coatings and morphological characteristics.



Alesik, Dreamstime.com



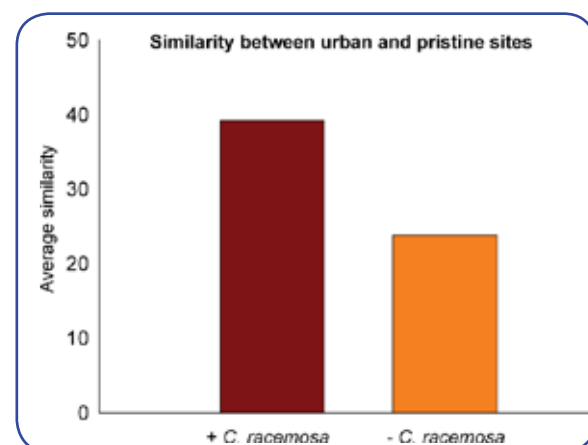
- » The estimated costs for shipping of mitigation measures (anti-fouling coatings and Ballast Water Treatment Systems) are between 1.6% and 4% of total shipping costs depending on the type of ship. This includes the current mitigation costs and the costs due to new legislation and guidelines if implemented in the coming years. These estimates must be regarded as very preliminary and further research is needed in the future.
- » The projected change in temperature for the Mediterranean in the A2 scenario (+1.0 degrees) could decrease seasonality of tourism in Catalonia, increasing the number of tourists in winter, spring and autumn. In summer higher temperatures could be less favourable to tourists.
- » In a Catalanian case study on tourism, installation of wind farms in front of beaches is likely to have a negative impact on the number of beach visitors (10-13% less visitors). However, effects are very local as beach users indicate that they would visit other beaches close by. The local effects of wind farms depend on their size, distance from the coast, and morphology of the coast.
- » Tourists in the Dutch Wadden Islands are willing to pay approximately 80 million euros per year to avoid the effects on the number of birds, seals and wind turbines that would be observed under the A2 scenario. This is a substantial part of the current value of the Dutch Wadden Islands for tourism (approximately 17%). The attitude of tourists towards wind turbines is partly dependent on nationality and political culture. In the Dutch Wadden Sea significant difference was found between Dutch and German tourists in their Willingness-To-Pay (WTP) to avoid wind turbines visible from the shore.
- » The application of a model for management of invasive species to the Pacific oyster in the Dutch Wadden Sea shows that optimal policies (Do Nothing, Immediate Eradication or Partial Removal of the stock of an invasive species) depend heavily on the costs of control.
- » If policymakers wish to increase the stability of international fisheries agreements under changes in stock location, then mechanisms could be put into place to encourage further deviation subsequent to any deviation by one of the countries, thereby forcing countries who are considering a deviation to consider the consequences of the breakdown of the whole coalition. Fishing countries would have to pose credible threats of further deviation from international fishing agreements in order to promote stable coalitions. This would limit the expected payoffs for potential deviators and hence increase the stability of agreements.
- » Stakeholders from the Gulf of Gdansk tourism sector consider proper spatial planning to be the main solution for conflicts between tourism and environmental protection. Existing problems in this area are ascribed to the lack of proper spatial management both at sea and on land. Stakeholders commonly viewed NATURA 2000 as an obstacle for economic development in general, and for tourism development in particular but this is largely due to ignorance of the functioning of the network and what is allowed within it.





### D4.1.1 Synthesis report of the VECTORS findings that are relevant to the issues of the Western Mediterranean Regional Sea

The Western Mediterranean Sea (WMS) is characterised by a number of pressures, the main one being tourism, as well as a number of more specific pressures such as, coastal and lagoon pollution, eutrophication linked with algal blooms, and the effects of fishing, particularly bottom trawling on benthic ecosystems. Global change in the WMS facilitates the arrival and spread of tropical invaders, a phenomenon that has increased in importance in recent years and is expected to have detrimental effects on marine ecosystems including biodiversity and fisheries. Among non-native species, a number of exotic seaweeds and algae are currently present in the WMS, along with many invertebrates and fish species. While tropical invasion has been a common phenomenon for decades in the eastern Mediterranean Sea ("Lessepsian migrants"), this is now starting to expand to the WMS as well, compounded by the entry of exotic species of Atlantic origin through the Gibraltar straits.



Despite the high eutrophication levels present in coastal areas in the WMS, the impact of macroalgal blooms has been little studied in this region. Systematic review suggests that macroalgal blooms have a strong, negative and statistically significant effect on species richness in marine and lagoonal assemblages in the WMS. *Caulerpa racemosa* was among the most noxious invader, posing a serious threat to biodiversity in the WMS, which is characterized by a high level of endemism. Specifically, its presence did not affect sites that were already impacted by high human pressure, but it did have a strong negative effect on pristine habitats. Certain species of invasive seaweeds, considered to be ecosystem engineers, were found to have negative effects on species richness and diversity.

Coupled modelling and experimental work identified temperature as the likely driving factor for (i) the current and potential future invasion of a case study non-native fish species (*Siganus rivulatus*) at the expense of its native counterpart (*Sarpa salpa*), (ii) changes in the seasonal migration of fish species between the sea and Mediterranean lagoons, (iii) future changes in distribution of pelagic fish along the Catalan coast, with the low-value *Sardinella aurita* outcompeting *Engraulis encrasicolus*, with important economic consequences for fisheries, and (iv) changes in the distribution of endemic bivalves (*Pinna nobilis*). Furthermore, environmental modelling shows that rocky shores may not be as affected by environmental fluctuations as commonly thought.

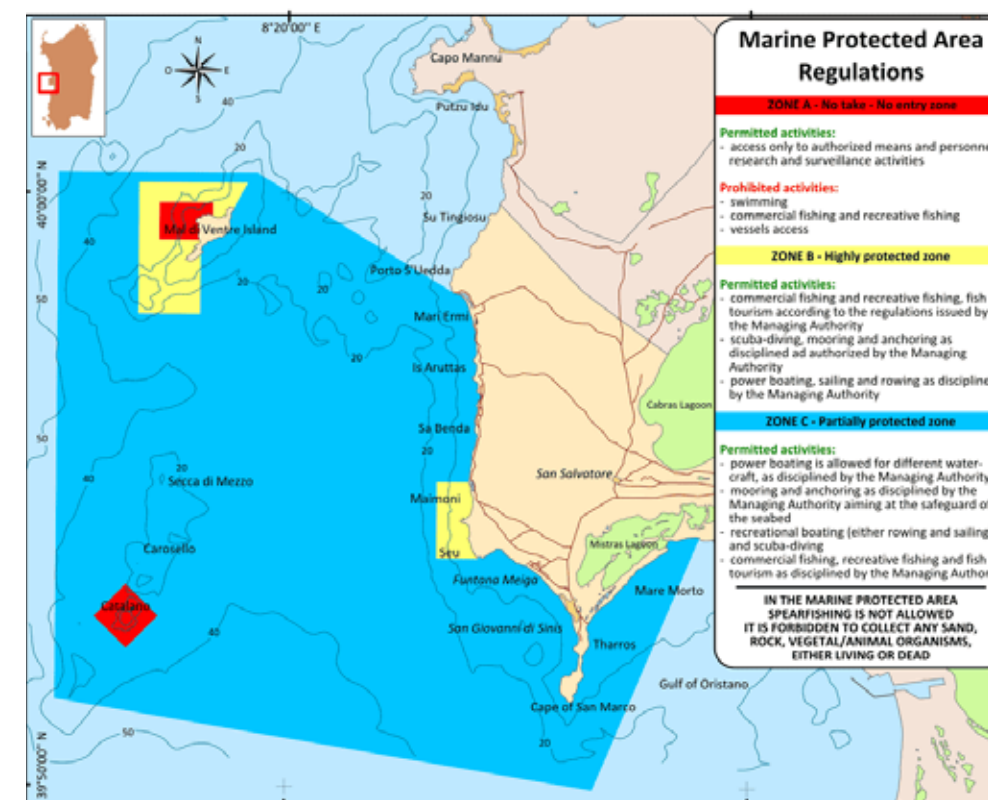
In addition to invasions through water bodies, for example via the Suez canal, certain species such as the ctenophore *Mnemiopsis leydi* may have invaded the WMS through other sources, such as ballast water brought in from the Atlantic Ocean. Evidence indicates that preventing further transfer of invasive species will require substantial additional efforts to promote cooperation and collaboration among governments, economic sectors, non-governmental organizations and international treaty organizations, in order for an effective control to be duly entered into force. As a precautionary principle, management strategies against invasive seaweed species should prioritize both pristine habitats and those characterized by intermediate human pressures, such as those situated between urban sites.

Recent data on the jellyfish species *Pelagia noctiluca* show that its outbreaks have increased in frequency in the last two decades along the Italian coast, likely due to large-scale hydrodynamic changes and global warming. Jellyfish outbreaks can have a major impact on the environment and society of the WMS, including fisheries and tourism, in addition to imposing additional costs on the local health system. The management of jellyfish outbreaks still requires further coordinated research efforts in order to work towards a better understanding of the underlying ecological mechanisms. This must be combined with the adoption of an effective prevention policy, mitigation strategies, and the appropriate planning of health services at tourist hotspots. Various scenarios have been developed in order to provide policymakers and managers with tools for predicting the economic and societal impacts of jellyfish outbreaks. The use of real-time information of the presence/absence of jellyfish can be a fundamental tool for managing and controlling the impact of jellyfish on tourism.



A platform based on systems modelling was developed for assessing how changes to the macrobenthos will affect populations of species targeted by fisheries. This information can be used to facilitate the control of fishing activities and promote responsible management.

In case studies, the presence of MPAs was found to be perceived positively by the main stakeholders because MPAs have a role in mitigating the effects of negative changes on the marine system and provide non-market goods and services to society as well as market benefits to local stakeholders. A number of recommendations relating to the development of MPAs have been put forward including the need to increase awareness of the importance of MPAs through environmental education for both adults and young people.



The Marine Protected Area of Penisola del Sinis - Isola di Mal di Ventre (Sinis MPA): location, zoning and regulation, and the northern sectors of the Oristano Lagoon-Gulf System, western Sardinia, Italy





### D4.2.1 Synthesis report of the VECTORS findings that are relevant to the issues of the North Sea Regional Sea

The North Sea research made key bridges between physical, ecological, economic and social science to better understand drivers of change in marine systems.

#### Mechanisms and Impacts

A variety of outbreak forming species, from macroalgae to gelatinous plankton, was examined. A key focus was to explore the potential impacts of these species on various facets of the North Sea food web including changes in productivity and the transfer of energy from lower to upper trophic levels including commercially important species. Biological and, in some cases, economic consequences of the establishment of invasive alien species (IAS) were examined with emphasis on IAS capable of transforming coastal habitats (coastal habitat engineers), such as the Chinese mitten crab (*Eriocheir sinensis*) and the Pacific oyster (*Crassostrea gigas*), which is also an important aquaculture species. Field and laboratory research on the ctenophore *Mnemiopsis leidyi* has advanced our process knowledge of the spread of IAS and the key factors such as temperature controlling their population dynamics and potential food web impacts. Temperatures  $<7^{\circ}\text{C}$  prohibit the growth of young larval *Mnemiopsis*, whereas feeding rates increase dramatically from 15 to  $25^{\circ}\text{C}$ .

Research examined causes and consequences of changes in the distribution and productivity of species in the North Sea. This included compiling existing and collecting new data (via a dedicated VECTORS research cruise) on fish, plankton, and habitat parameters to ground-truth models predicting the distribution and productivity of various species from zooplankton to fish.

A meta-analysis and visualization of projected hot spots of ecosystem change in the North Sea provided a simple picture of spatially-explicit model projections converting complex, detailed ecosystem-level research into a simple product focusing on explicit questions: where is change happening, and how big is it? The tool allows areas of expected change to be plotted against spatial management options to gauge potential matches and mismatches in management targets and objectives, identifying areas where conflicts may arise due to ecological sensitivity and high infra-structure or exploitation needs. The vast majority of the areas of North Sea expected to be most sensitive to climate-driven changes in ecosystem dynamics (and nutrient loading of coastal areas) do not correspond to planned conservation sites and, are thus, being overlooked. This finding has important implications for management of the North Sea ecosystem and the sustainable use of its resources.

#### Implications for environment and society:

Interdisciplinary research was conducted within VECTORS combining both smaller (case study / area-specific) and larger (North Sea-wide) scales.

A case study of the Dogger Bank, a unique environment in the central North Sea shared by four countries, highlights the importance of integrating ecological, economic and social science to examine drivers of change and their consequences for natural resources. Projected bio-economic impacts on fisheries of climate and potential spatial conflicts between fisheries, renewable energy (wind farms) and conservation were examined. Interviews with national and EU stakeholders and policymakers identified important differences in views and conflicting interests in that region.

The case study in the Eastern Channel, one of the most important shipping gateways, integrated ecological and economic research to thoroughly explore drivers of change in species with unique habitat requirements (e.g. flatfishes). Commercially important species may be sensitive at different stages of their lifecycle to a variety of (seemingly separate) drivers acting in different (coastal to offshore) habitats. Interviews revealed the impacts of interacting drivers such as shipping and aggregate extraction on the behaviour of individual fishers and specific fishing fleets.



The results of North Sea VECTORS work are relevant to management in several ways.

- » The optimal management strategies of IAS not only need to account for spatial dynamics of the spread of coastal species but also the costs and potential commercial benefits, particularly in the case of the Pacific oyster.
- » Spatial mapping tools have been developed to combine and summarize the estimates from various models into simple, integrated data products that can easily be communicated to, and used by, managers and policymakers.
- » Strategies to understand and predict conflicts from users across sectors (fishing, renewable energy, conservation) have been documented within a region (Dogger Bank) sharing the EEZs of four nations.
- » Models predicting human responses to changes (e.g. fishers' behaviour based on economics and ecology) have been developed. This critical work step allowed bio-economic and end-to-end models to be created and used in future projection modelling (VECTORS future scenarios) in the North Sea region (reported in Deliverable report 4.2.2).



### D4.2.2 Scenario modelling of the North Sea under the influence of multiple drivers with recommendations for regional adaptive management strategies addressing EU policies

Modelling activities were undertaken in the North Sea (under the VECTORS Scenarios) that can provide advice for the management of marine resources that are influenced by a variety of manageable (e.g., fishing, energy, shipping) and non-manageable (climate) pressures.

Climate-driven projections from three species distribution models (SDMs) were used to alter the strength of interaction (spatial overlap) between predators and prey within a multi-species model currently used for fish stock assessment in the North Sea. Although the impacts of climate-driven changes on the distribution of most species (and hence most predator-prey interactions) were predicted to be relatively small ( $< 10\%$ ), both the future magnitude and direction of changes in trophic interactions differed among the three SDMs. This highlights the need to incorporate structural uncertainty (different types of models producing similar estimates) when providing advice on climate-driven changes in distribution for ecosystem-based management. Modelling activities underscored the importance of analysing the combined impacts of not only climate-driven changes in fish distribution but also the future economic and policy developments (area closures, fuel/fish prices) when providing advice for marine spatial planning and fisheries in the North Sea. An important finding was that the increase in fuel and fish prices associated with VECTORS future scenarios had a much higher impact on the economic performance of the fleets than either climate-driven displacement of fish or the spatial closures associated with conservation and renewable energy. Hence, economic aspects of future scenarios need to be carefully considered.

Atlantis models were built and parameterised for the Eastern Channel and the whole North Sea. These models were created as tools to investigate the dynamics and the processes dominating these ecosystems and their living marine resources. The Atlantis model in the Eastern Channel focuses on processes influencing the productivity of two commercially important flatfishes, sole and plaice. The calibration process revealed the importance of coastal areas and high nutrient inputs from estuaries for the maintenance of their production, with discards appearing to play an important role in the food web dynamics. VECTORS has described the rationale for parameterization choices for creating an Atlantis model. The food web in the North Sea model is highly complex (especially compared to other existing models) and further steps are still required to improve this first version of the model. However, it has been possible to undertake simulations under VECTORS future scenarios to examine losses of fishing grounds due to wind farm installation and conservation (NATURA2000) areas (D5.1.3).



### D4.3.1 Synthesis report of the VECTORS findings that are relevant to the issues of the Baltic Sea

Eutrophication and pollution are among the major threats to the environment of the Baltic Sea, affecting the productivity and overall health of the ecosystem. With some of the busiest shipping routes in the world going through the Baltic Sea there is a high risk of non-indigenous species being introduced, which may disturb local ecosystems. In addition to human activities, the Baltic Sea ecosystem structure and functioning is influenced by climate change as many species inhabiting the Baltic are close to their tolerance limits for distribution and reproduction, which makes them vulnerable to changes in the environment. As is the case in the other regional seas studied, fishing is a common and important driver of change. Tourism is locally important, though it is much less intensive than in other regions, such as the Mediterranean Sea. New drivers in relation to energy production and transfers, such as wind farms, are emerging as in all of the regions studied in VECTORS.

#### Mechanisms and impacts:

The Invasive Alien Species, that are currently established and widespread in the Baltic Sea, have been introduced predominantly through ship's ballast water and hull fouling. Other pressures such as pollution, eutrophication, and climate change modulate the resistance of communities and may facilitate the establishment of non-indigenous species (NIS). The dynamics and impacts of NIS is strongly context specific. In general, all species invasions have resulted in increased biomass of exotic species and reduced biomass of some native taxa. However, our current knowledge of the nature and magnitude of ecosystem impacts of even the most widespread non-indigenous species in the Baltic Sea suffers major limitations due to taxonomic and sub-regional bias.

Investigations into outbreak forming species have largely focused on jellyfish. Man-made artificial hard substrata, e.g. offshore wind farms and other fixed offshore installations have the potential to significantly increase the settlement probability of jellyfish and increase their abundance. Jellyfish act as predator for zooplankton and a competitor for planktivorous fish. Thus, their high abundances might cause reductions in the abundance of zooplankton and commercial fish larvae.

Distribution and productivity in the Baltic Sea is affected by multiple drivers. Climate affects the productivity of both commercial and non-commercial fish via changes in the hydro-climatic environment. Changes in nutrient concentrations can also affect fish production, although historically the observed increase in nutrients does not seem to have substantially enhanced the production of forage fish in the Baltic Sea. New threats from pollution may become important if heavy metals from sediments are released and taken up in biota. Offshore wind farms may lead to an increase in the biomass of benthic invertebrates such as blue mussels, which can lead to local anoxia in the direct vicinity of wind farm piles. Fishing affects the relative abundances and distributions of predator and prey species, resulting in spatially distinct patterns of growth and survival.

#### Implications for environment and society:

In the future, the drivers that can lead to the introduction of NIS are likely to intensify. For the Baltic Sea, a significant increase in the number of NIS and the resultant new ecosystem functions will translate into large scale changes in ecosystem functioning and services.

Outbreaks of algae and poor water quality due to eutrophication are continuous problems, and only marginal improvements in the eutrophication status in some areas have been observed in recent years. Outbreaks of jellyfish, due to the establishment of offshore wind farms, could possibly increase in the future which may impede coastal tourism, cause clogging of fishing nets and may reduce fish catches due to predation on fish larvae.

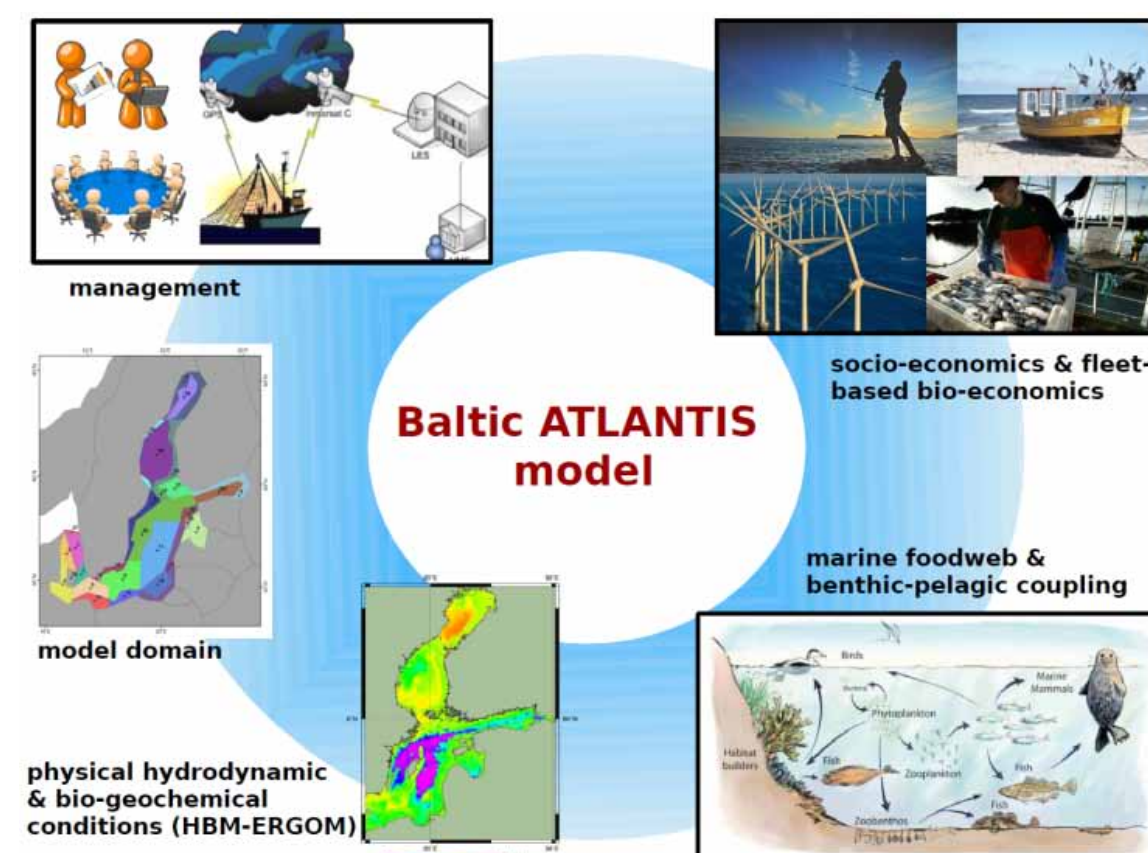
Changes in distribution and productivity of species (due to fishing, climate etc.) can lead to large scale changes in the entire ecosystem structure and functioning as well as the provision of goods and services, such as fisheries yields.

#### Relevance for management:

- » The AquaNIS information system, developed in the course of VECTORS, is available to assemble, store and disseminate comprehensive data on alien species, and assist in the evaluation of the progress made towards achieving management goals, e.g. the EU Marine Strategy Framework Directive and the International Convention for the Control and Management of Ship's Ballast Water and Sediments. The Baltic module on 'Invasion events' is available online and is freely accessible.
- » Simulations of future scenarios of fishing, nutrient levels, and climate change can assist in setting appropriate targets, while taking into account ecological interactions.
- » VECTORS results demonstrate the need for Marine Spatial Planning and spatially resolved management measures to tackle changing distributions of species and increasing multiple human activities in the management.
- » A holistic modelling tool (Atlantis) has been set up for the Baltic Sea that has the potential to serve as the most comprehensive integrated, dynamic, bio-economic modelling platform available and can be used for medium to long-term strategic advice on management of marine resources in the Baltic Sea region in the future.



Brown green filamentous algae, Sopot, Southern Baltic. Eutrophication and pollution are among the major threats to the environment of the Baltic Sea



A schematic diagram illustrating the structure and processes considered in the Baltic ATLANTIS model.

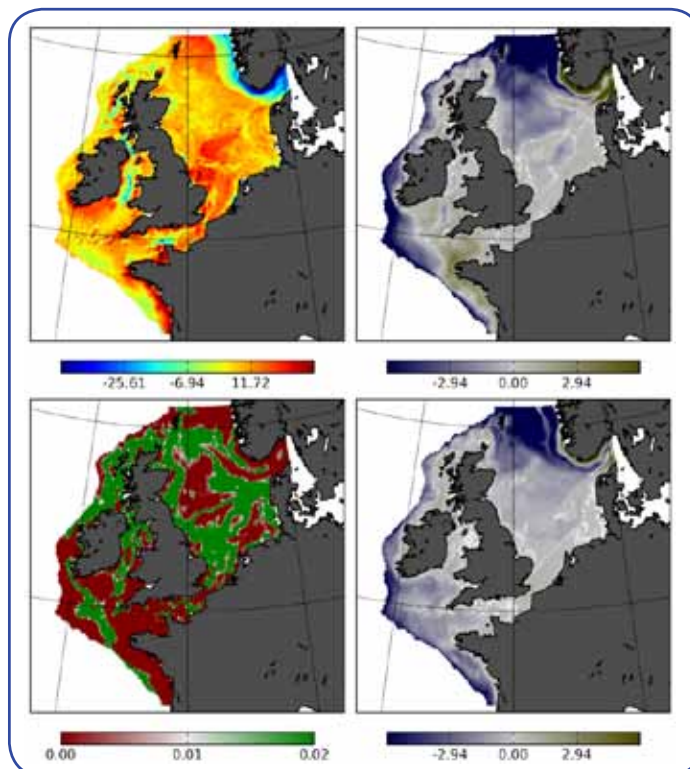


### D5.1.1 Future scenarios of the biogeochemistry of the three regional seas

Hypothetical future projections were modelled for the three regional seas under two VECTORS future scenarios (A2-National Responsibility and B1-Global Community) to inform on the relative vulnerability of the lower trophic level of the marine ecosystem to the investigated drivers of change (climate change, ocean acidification and river discharge). The drivers were injected into the model simulation by the means of open ocean, atmosphere and river boundary conditions.

Maps of change of key ecological indicators of the system (such as nutrient levels or community production) and the statistical significance of these changes have been made available for simulations representing a ten-year period in the middle of the 21st century. These delivered the environmental conditions for the simulated scenarios to drive the modelling activities of WP 5.2 building on the lower trophic level simulations, as well as additional modelling activities and ecosystem assessment specific to the Regional Seas.

Community production for NW European shelf ( $\text{mmol/m}^2$ ). Top Left: present day mean, Top Right: A2 change with respect to present day, Bottom Right: B1 change with respect to present day, Bottom Left: p-value of significance for difference between A2 and B1



### D5.1.2 Future distribution and productivity of marine fish and invertebrates

Eleven different modelling applications were undertaken, covering 150 European marine species, towards providing future projections of distribution and productivity in marine organisms. They ranged from models based largely on correlations, to fully mechanistic approaches that require detailed biological knowledge obtained from laboratory experiments. Most were applied in the North Sea or western Mediterranean. Some of the models focussed specifically on the proliferation and spread of invasive, non-native and outbreak forming species. Models have been used to investigate the possible consequences that might follow as a result of future climate change, but other human 'stressors' have also been examined, including various fishery management scenarios, as well as the introduction of offshore wind farms and marine protected areas. Based on the analyses carried out, some important observations include:

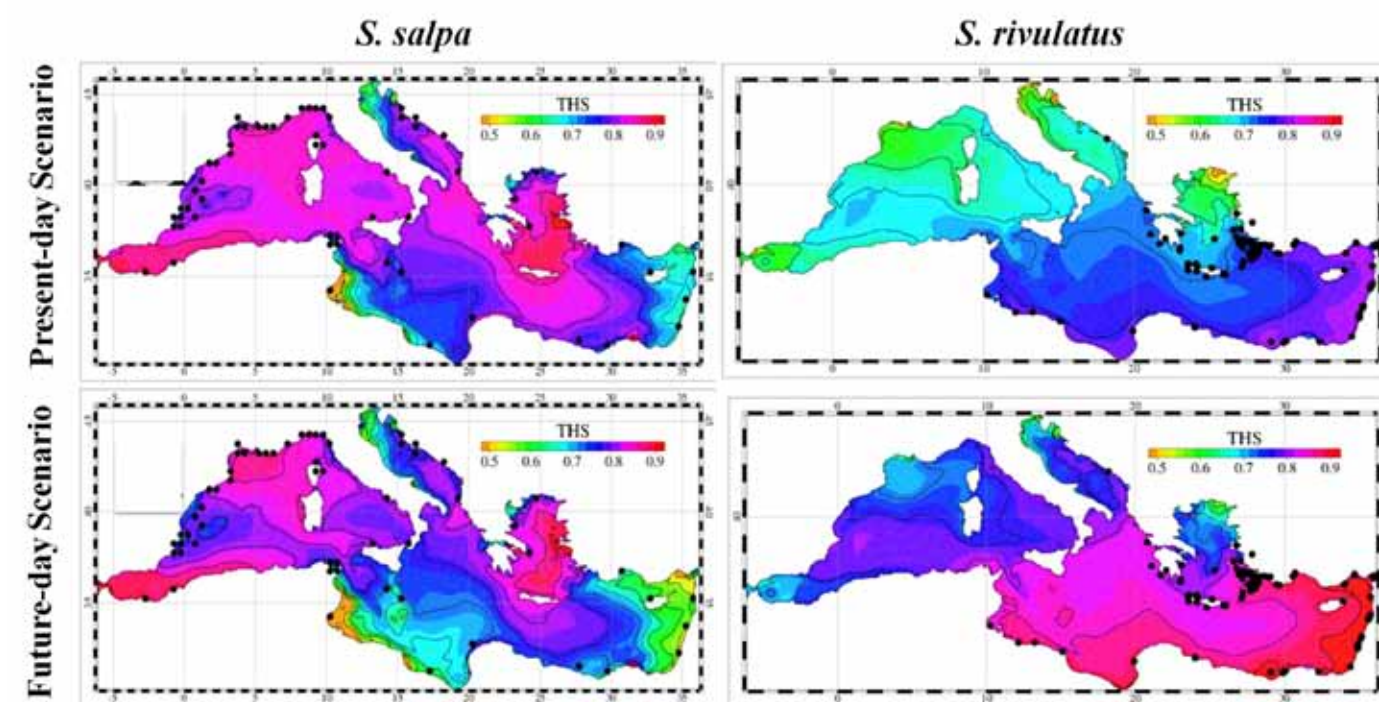
- » The distribution of many fish and invertebrate species are projected to move northwards over the next 50 years in response to anticipated climate change. Overall, median rates of shift will be significantly greater for pelagic rather than demersal fish species, at 277 km compared to 168 km respectively.
- » The anticipated northward shift in the distribution of species will have consequences for marine fisheries, but also the efficacy of certain marine protected areas. It is suggested that North Sea countries may witness a decline in certain 'traditional' fishery species such as cod, but the arrival of other exploitable resources including seabass, squid and anchovy.
- » Detailed knowledge of animal physiology from laboratory experiments can be taken up and used in models to predict changes in 'habitat suitability' as a result of rising seawater temperatures or changes in food

availability. In turn, this information can be used to determine 'winners' and 'losers' at particular localities, including whether or not a non-native species (such as *Siganus rivulatus*) is likely to out-compete a native organism (such as *Sarpa salpa*).

- » Complex models that incorporate predator-prey dynamics can be used to investigate the indirect consequences of management actions, for example as a result of fishery displacement following the introduction of spatial closure measures or changes in predator-prey overlap as a consequence of climate change. VECTORS provides an overview of fishery and food-web impacts following introduction of Special Areas of Conservation (SACs) under the EU Habitats Directive in the North Sea, and of planned large-scale wind farms on the Dogger Bank.
- » A suite of modelling tools is available, and has been applied, to firstly 'predict' the potential geographic range (now and in the future) of an invading non-native species, once it has been introduced and also to determine the likely food-web consequences following establishment.

A key finding is that different model types, but also relatively similar models, can yield equally plausible but substantially different projections of species distribution. It is recommended that an 'ensemble' approach be taken, where there is no assumption that one model is 'best' and believed above all others. Rather, that significant insight can be gained by using outputs of all models together, acknowledging that some predictions will be robust across many different model types and hence indicating greater confidence in these results, whereas other features may be predicted by only one model, and thus would be more uncertain.

It is suggested that any model can only ever achieve two of three desirable model attributes: realism, precision, and generality. Model creation, requires a trading-off of one of these attributes in favour of the other two, however, this is often in conflict with the desires of end-users (i.e. managers or policy developers).



Predicting future thermal habitat suitability of competing native and invasive fish species: Thermal habitat suitability computed for the whole Mediterranean Sea from basin-scale model results. Dots represent field observations of current fish distribution for the native *Sarpa salpa* (a species of sea bream) and the invasive *Siganus rivulatus*.



### D5.1.3 Holistic framework(s) for assessing multiple drivers

Understanding and quantifying the spatial distribution of human pressures (mapping and modelling) is key to the evaluation of trade-offs between human uses of the oceans and protection of ecosystems and the services they provide. A number of different modelling techniques have evolved in order to examine 'trade-offs' and three of these (Atlantis, Ecospace and OSMOSE) were applied within VECTORS.

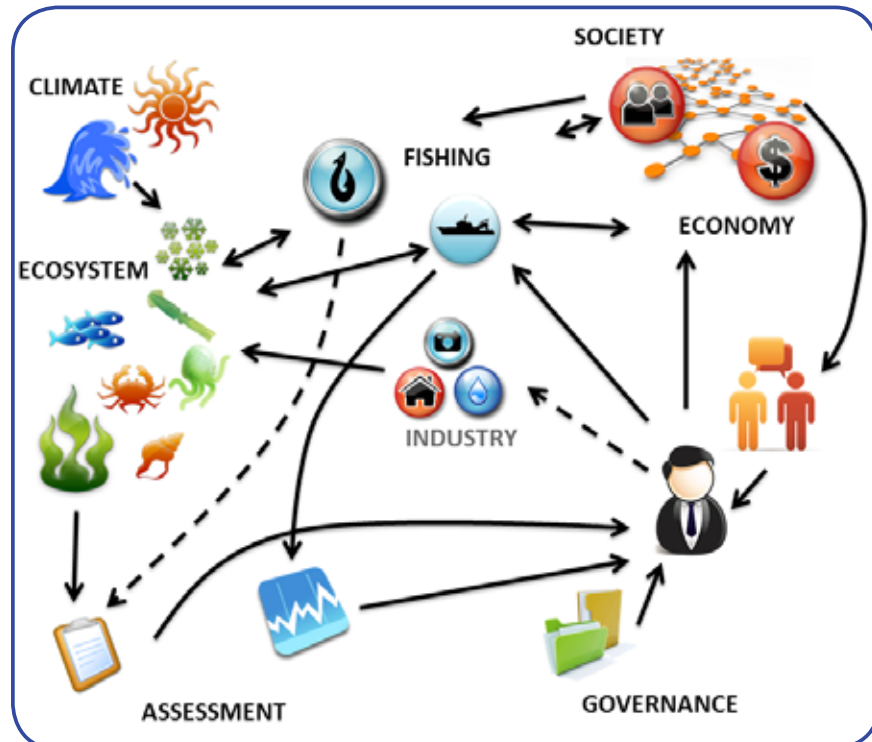
At the instigation of the VECTORS project, because of its complexity, it was intended that Atlantis would be applied only within the context of the North Sea. However, once the project was underway it was realised that Atlantis might offer wider utility, in particular it could provide a common integrative platform across all case study regions in order to examine multiple interacting pressures, where this would otherwise be impossible. Consequently VECTORS has achieved considerably more than originally envisaged and there are now, four fully-parameterised and functioning Atlantis models for the eastern English Channel, the Baltic Sea and Sicilian Channel as well as the North Sea.

A key strength of Atlantis is its modular construction. Atlantis incorporates alternative sub-models which characterise the biophysical environment, industry/stakeholder interactions, socio-economic drivers, management responses, and the monitoring or stock assessment processes. The North Sea Atlantis model was used to evaluate two future scenarios involving spatial closures for the purpose of nature conservation and construction of offshore wind turbines. For cod, plaice and sole an increase in commercial landings overall was anticipated when certain regions were closed to fishing, whereas for whiting and brown shrimp a decrease in fishery landings was determined.

In the Baltic Sea, the VECTORS Atlantis model was used to explore implications of changes in nutrient regimes (eutrophication). Point source inputs of nitrogen and phosphorus were manipulated under two scenarios of nutrient reduction to investigate indirect consequences elsewhere in the food-web. Simulations resulted in reduced fish production in the region although the magnitude of effects was very small (despite very dramatic reductions in nutrient inputs). Simulations of this type are not possible using any of the other holistic modelling approaches (OSMOSE, Ecospace etc.) and hence, this is a truly unique capability of Atlantis.

In the Mediterranean, an Atlantis model was created for the Straits of Sicily and used to investigate the consequences of future climate change as well as an increase in nutrient run-off from rivers. The model proved insensitive to future increases in nutrients discharged to coastal areas, and also relatively insensitive to the projected temperature increase, which for the Strait of Sicily area is on average 0.6°C over the next 50 years, a relatively low increase compared to the rest of the Mediterranean Sea as predicted by POLCOMS-ERSEM (VECTORS D 5.1.1).

Now that the underlying models have been constructed there is great potential to conduct further explorations and continue development of the models in future EU or national projects, so that they can be used to their full potential to assist development of ecosystem-based management (EBM).

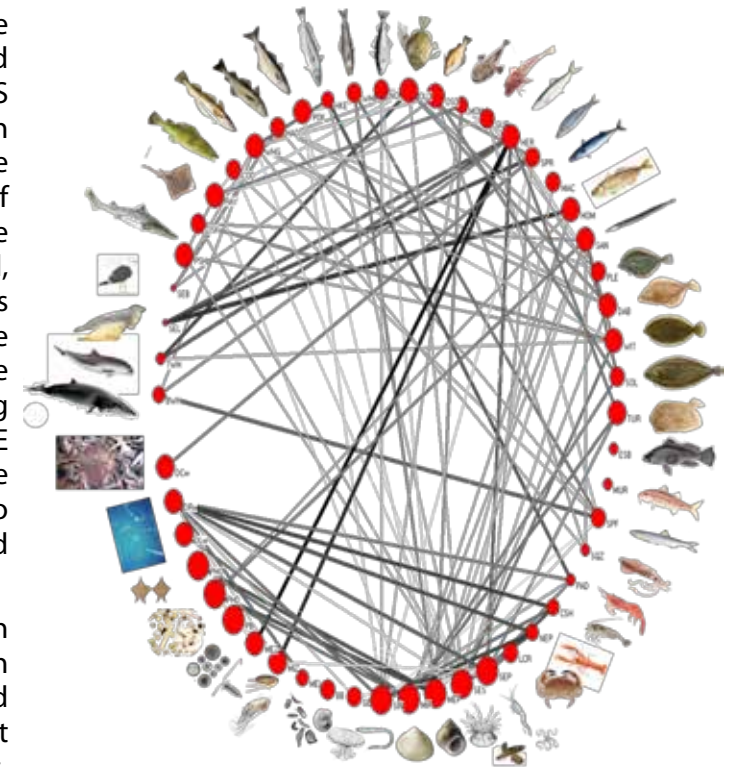


Schematic representation of the ATLANTIS modelling framework (Beth Fulton, CSIRO).

OSMOSE (Object-oriented Simulator for Marine ecOSystem Exploitation), a multispecies and Individual-based model (IBM), was used in VECTORS to examine interactions between 14 species of fish to determine multispecies management reference points following the simulated implementation of different fishery management practices within the context of the Eastern English Channel. In the model, some species appear to be at their sustainable levels (sole, spotted dogfish and mackerel), others are under-exploited (pouting, horse mackerel, sardine and herring) whereas plaice, red mullet, cod, whiting and squids are in an overexploitation state. OSMOSE was also used to conduct simulations of marine protected areas (MPAs), fishing moratoriums, and to examine the combined effects of climate change and overexploitation.

Ecospace is a development of the widely-known Ecopath-with-Ecosim (EwE) modelling suite. An Ecospace model for the North Sea was developed comprising 68 functional groups and 12 fishing fleet categories defined by EU Data Collection Regulations. This model was used to investigate the consequences of the introduction of large scale marine protected areas and offshore wind farms. Results highlighted that displaced fishing effort can be a major problem. In the model, an increase in the target species was observed within the MPA, but catches were higher elsewhere, and thus the stock as a whole often suffered when an MPA (or a wind farm) was introduced.

There are many features that Atlantis and Ecospace have in common, including habitat allocation, they both incorporate the full food-web from detritus up to marine mammals, they both include a fishing fleet redistribution model etc., and in some instances they are able to test similar management scenarios. However Ecospace is inherently less demanding and is more accommodating of easily derived observational datasets. By contrast, Atlantis is more capable with regard to management strategy evaluation (MSE) and can investigate the consequences of a greater number of human pressures.



Feeding interactions in the North Sea based on stomach content (Marc Hufnagl, UHAM).

### D5.1.4 Decision-support framework with Multi-Activity Control Rules (MACR) developed and applied to specific case study regions

The conservation performance of management strategies developed to mitigate the cumulative effects of fishing and aggregate extraction activities on key Eastern English Channel ecosystem components (flatfish species and benthic taxa) was evaluated. In order to do so, a complex, spatially explicit, model of two flatfish populations and three benthic groups was built using the ISIS-Fish modelling platform. Results obtained suggest that a Harvest Control Rule can help the recovery of strongly depleted biomasses for the modelled fish species. The current ecosystem state should allow attainment of management goals but the level of natural variability in environmental parameters that can be tolerated is low. There was no evidence of positive effects of MPAs on fish populations, either at the scale of the eastern English Channel or at smaller scales gathering several bays on the French and English coasts. In contrast, effects of MPAs were very important for benthic taxa because they are comparatively immobile. MPAs can maintain high benthos abundances in protected areas, but at the cost of severely depleted abundances in adjacent areas that are not protected.

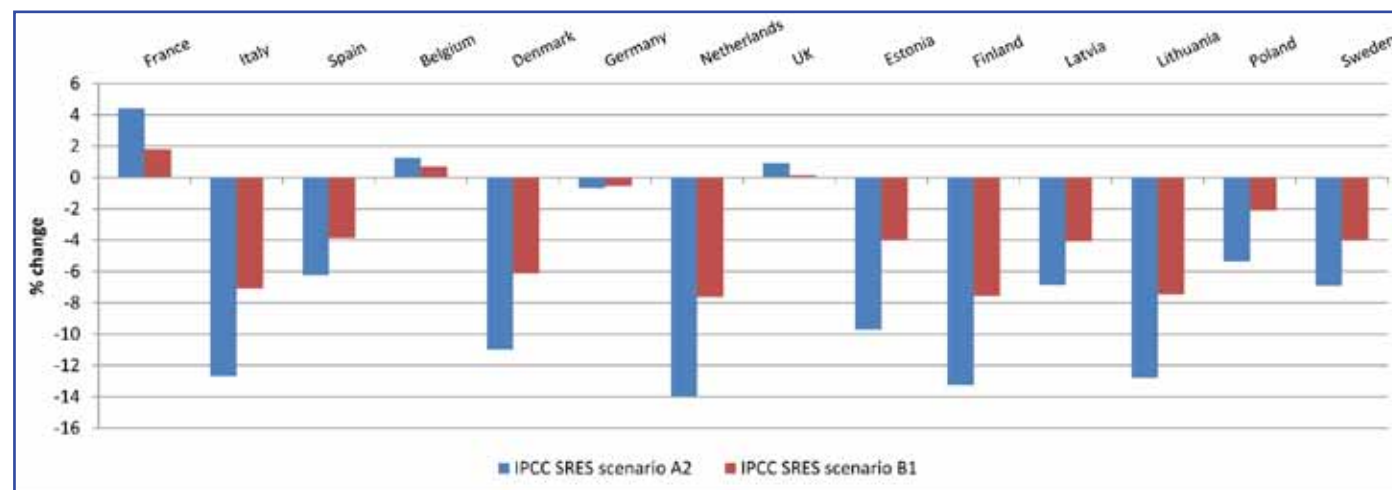
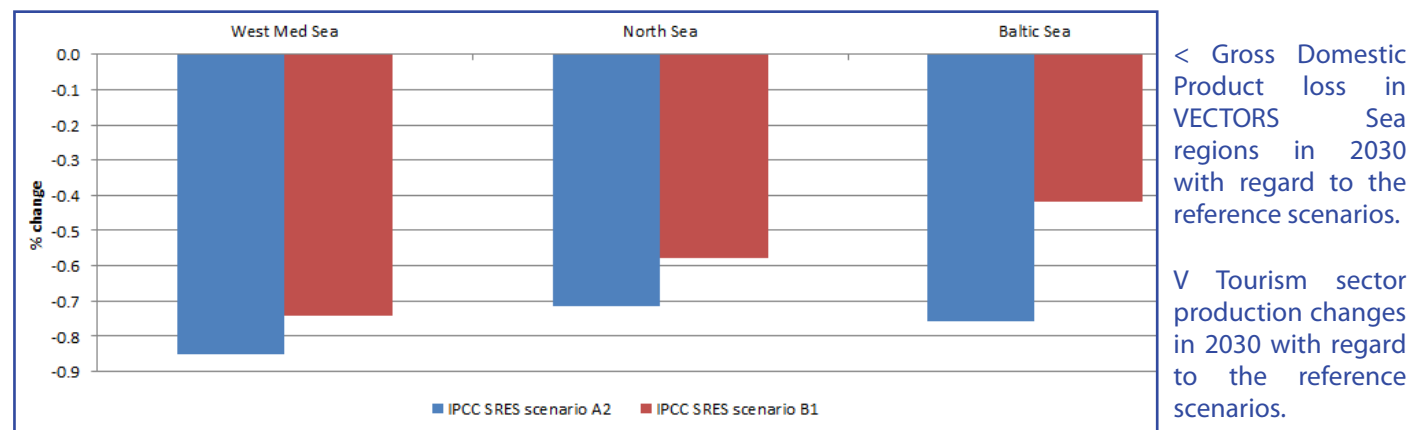


### D5.2.1 ICES modelled social economic impact assessment for the future

The potential macro-economic effects of future changes in the EU marine ecosystem in the medium term (2030) were modelled using ICES, a computable general equilibrium (CGE) model. Effort focussed on changes potentially affecting the fishing and the tourism sectors under the VECTORS scenarios and varying the future trends of population, Gross Domestic Product (GDP), prices, as well as the overall impact on the environment. Sector-specific economic impacts were channelled through increases in fishing effort, due to the lower availability of commercial fish species, and a decrease in tourism demand following deterioration of marine ecosystem quality.

Impacts on EU coastal countries GDP are negative and larger when the tourism sector is affected. This is explained by the much higher contribution of tourism than fisheries in the production of value added. Negative impacts are also larger in the National Enterprise A2 than in the Global Community (B1) scenario. The largest GDP losses due to adverse impacts on fisheries are experienced by Spain (-0.13%), those related to tourism by Italy (almost -1%). Percent changes in sectoral production are notably larger than GDP ones: the largest contraction in fish sector production occurs in France (-24.7%). Notable decreases in coastal tourism demand occur in Spain and the Netherlands. In general the Western Mediterranean is the most adversely affected region, whereas the Baltic Sea denotes a particular vulnerability to losses in tourism value added. North Sea countries experience smaller losses.

The results indicate that changes in marine ecosystems can have wider macro-economic effects and although these may appear to be small in the context of national GDP they are likely to be of greater significance when the different maritime sectors are considered and to vary among the EU's regional seas.



### D5.2.2 Implication of possible future developments for international, interregional, and intersectoral cooperation in marine policy

The implications of invasive alien species (IAS), outbreak forming species (OFS), and changes in species productivity for existing modes of cooperation (international, interregional or intersectoral) in marine policy have been investigated using game-theoretic approaches. By far the most important modes of cooperation at risk from IAS, OFS, and changes in species productivity are international fishery coalitions, which are threatened by climate-induced northward shifts of fish stocks and sudden, catastrophic stock collapses, partly driven by fishing pressure. In line with earlier findings in the game-theoretic literature, shifts in stock abundance destabilize coalitions if the willingness and ability to fish becomes more evenly distributed over the countries involved. However, VECTORS also found that if countries are more forward-looking, i.e. they consider that if they leave the coalition, other members might do the same, the coalition is more stable than if countries have a more 'myopic' outlook. The risk of stock collapse can also be a stabilizing factor, provided of course, that those countries are aware of the risk.

### D6.1 Understanding stakeholder and policymaker needs for successful marine environmental management

A comprehensive and technical review has been undertaken of 1) the current international and European law related to three of the key VECTORS drivers: energy, fisheries and alien species, and then of 2) the implementation of the relevant Conventions, Directives, Policy and Strategy documents into national frameworks to protect the marine environment of those member states with partners in VECTORS. The synthesis concentrates on the three regional sea areas. It includes:

- » A matrix of legal instruments and policy documents available to scientists/policy experts working on projects in the marine environment, which are relevant to the regional sea areas and also how they impact on the three key drivers.
- » A review of the international law including the fundamental marine law of UNCLOS, the Convention on Biological Diversity, the United Nations Framework Convention on Climate Control, Conventions to control pollution from ships and the dumping of other wastes, the Environmental Impact Assessment in a Transboundary Context (the Espoo Convention), the suite of Conventions, Strategies and Agreements designed to protect wildlife and habitats and the Regional Seas Conventions (OSPAR, HELCOM and Barcelona).
- » A detailed account of the relevant European legislation implemented to protect habitats and species, and the health, quality and protection of marine and coastal waters. As well as a review of related strategy documents and a summary of the Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) Directives.
- » A description of the national legislation enacting the European policy and law and the organisation(s) responsible for its implementation for each of the VECTORS countries

The views of stakeholders and policymakers on a wide range of marine governance issues in a number of regional sea case studies across Europe have been documented and analysed (on the basis of 69 semi-structured interviews and literature review). A case study approach was adopted through four detailed reviews in addition to a more general assessment of the main barriers to and drivers for successful European marine resource management, which was undertaken at the EU-level.

Although the case studies focused on four different locations, in three different regional seas, there were several common themes which emerged which also resonated with the general assessment of the main barriers to and drivers for successful European marine resource management. For example, conflicts between different stakeholders about the use of certain parts of the marine environment, and possible conflict resolution strategies. Conflicts were particularly intense between (would be) users and those stakeholders who would like to ensure as high a level of protection as possible for the marine environment. The EU-level study concluded that cooperation, dialogue and more integrated policies (ecosystem approach) are important elements for the better management and governance of the EU's regional seas.



## D6.2 Database of alien species presence within and in the 'vicinity' of representative EU ports

A database was compiled of alien species presence within and in the vicinity of representative EU ports. This knowledge on alien, cryptogenic and other (potentially) harmful species in ports can be used to alert the shipping industry to harmful species occurring in ballast water uptake zones in order to fulfil the obligations of the IMO Ballast Water Management Convention and to enable ballast water management related risk assessments. This knowledge is not comprehensive and therefore contributed towards identification of what needed to be done within VECTORS for the development of risk assessment procedures. A list of the most invasive species in the seas considered by VECTORS was made available for use in WP3 systematic reviews and many of those species also occur in ports.



## D6.3 Review of ballast water discharge risk assessment tools, and new decision support systems for EU ports to avoid aquatic species invasions

Support tools and solutions have been provided for four complex areas of shipping related to the management of their ballast water, i.e. (1) vessels and ballast water, and ballast water discharge assessment (BWDA), (2) international ballast water management (BWM) requirements and the situation in the EU seas, (3) ballast water risk assessment (RA) under the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention), and (4) BWM decision support system (DSS).

A generic ballast water discharge assessment (BWDA) model, based on vessel cargo operations and dimensions, has been prepared and tested. The model predicts whether or not a vessel will discharge ballast water, as well as assessing the quantity of ballast water to be discharged. The global ballast water discharges from vessels engaged in the international seaborne trade was estimated as 3.1 billion tons in 2013. The BWM Convention (and its supporting guidelines) as well as its implementation options have been reviewed. In the EU, different BWM approaches have been developed at regional levels and are of a voluntary nature (HELCOM/OSPAR/REMPEC BWM approaches).



Detailed, step-by-step risk assessment (RA) models, developed in VECTORS, strictly follow the BWM Convention and enable a selective BWM approach so that only those vessels carrying critical ballast water are required to conduct BWM. The risk level is a case-by-case RA result and the reliability of RA input data is of key importance. RA models are provided for exemptions from BWM requirements and for selective BWM measures, ready to be used by administrations.

As a case study, the RA model for exemptions was applied to intra-Baltic shipping considering different RA methods. As reliable species data is not available for the ports considered, and following the precautionary principle, no exemptions should be granted. To ensure data reliability, port baseline surveys and regular monitoring programs should be conducted during the BWM exemptions period as newly arriving species may influence the RA result and the exemption given may have to be revoked.

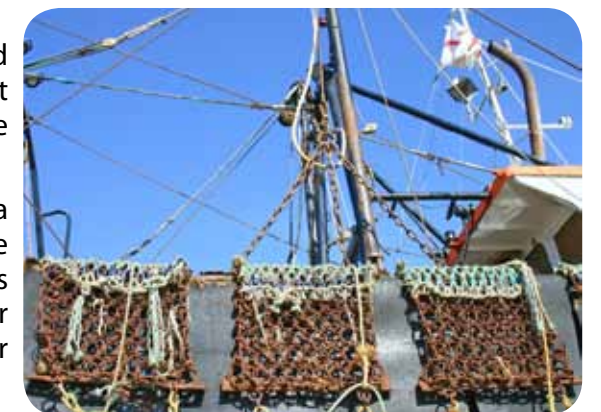
A detailed step-by-step Decision Support System (DSS) model was developed to provide transparency and consistency on BWM requirement decisions with the aim of improving environmental protection and reducing the BWM burden on vessels. The DSS model, validated with one year of ballast water discharge information from the Port of Koper, Slovenia, is ready to be used by administrations and other authorities involved in BWM related decision-making processes. In the Port of Koper, it is most likely that only vessels from outside the Adriatic Sea should be enabled to conduct BWE before they call into the port. The designation of a ballast water exchange area in the Adriatic Sea would open more options to conduct BWE. A critical situation arises in cases when a vessels' ballast water is assessed as posing an extreme risk because the BWM DSS would conclude that it would not be allowed to discharge unmanaged ballast water. This end point would hinder shipping in the case where a vessel needs to discharge its ballast water, but may be avoided by using ballast water reception facilities or by applying "emergency" ballast water treatment, which could be the addition of chemicals. However, in the latter case it would need to be demonstrated that the discharge of this chemically treated ballast is environmentally acceptable.

## D6.4 Develop risk assessments leading to best practice: Fisheries management

An assessment has been made of the efficacy of marine planning in minimising risk in the context of a case study on risk assessment of fishery management in a Marine Protected Area of the Western Mediterranean. Bow Tie analysis was developed as a tool to determine how risks of over-exploitation of the biological resource can be prevented and if not prevented, how they can be mitigated. Key benefits of the use of the Bow Tie approach for the fishery case study were:

1. It allowed a quick analysis of what has been done in terms of management of the biological resource throughout the years;
2. It will support the local MPA managers in their drafting and adoption of proper management plans that take into account possible repercussions if some of the factors involved in the sustainable use of the biological resources are overlooked.

Although this approach was considered to be successful as a proof of concept and demonstrated that the Bow Tie scheme is appropriate for mapping out causes, consequences, hazards and risks caused by and to fishery over-exploitation, further development is needed to determine the overall significance or acceptability of the causes and consequences.





## D6.5 Develop risk assessments leading to best practice: Resource exploitation – renewable energy

An assessment has been made of the efficacy of marine planning in minimising risk in the context of offshore wind farm developments in the North Sea. The Bow Tie method was used to assess risk in the case study of offshore wind power on the Dogger Bank as an example of an area primed for large scale wind farm development in the near future. Use of the Bow Tie approach was successful in being able to map out all aspects that are related to two particularly undesirable events, including ways of preventing and mitigating risk. These two events were:

1. The loss of renewable energy resources; the context of this Bow Tie was 'ways that climate change can cause the environment to affect the wind farm';
2. Changes to the environment in terms of the MSFD GEnS indicators; the context of this Bow Tie was 'ways that the wind farm can affect the environment'.

The Bow Tie risk assessment approach was demonstrated to have considerable strengths. Although this exercise was considered to be successful as a proof of concept and has shown that the Bow Tie scheme is appropriate for mapping out causes, consequences, hazards and risks caused by and to wind energy in the North Sea, further development is needed to determine the overall significance or acceptability of the causes and consequences.



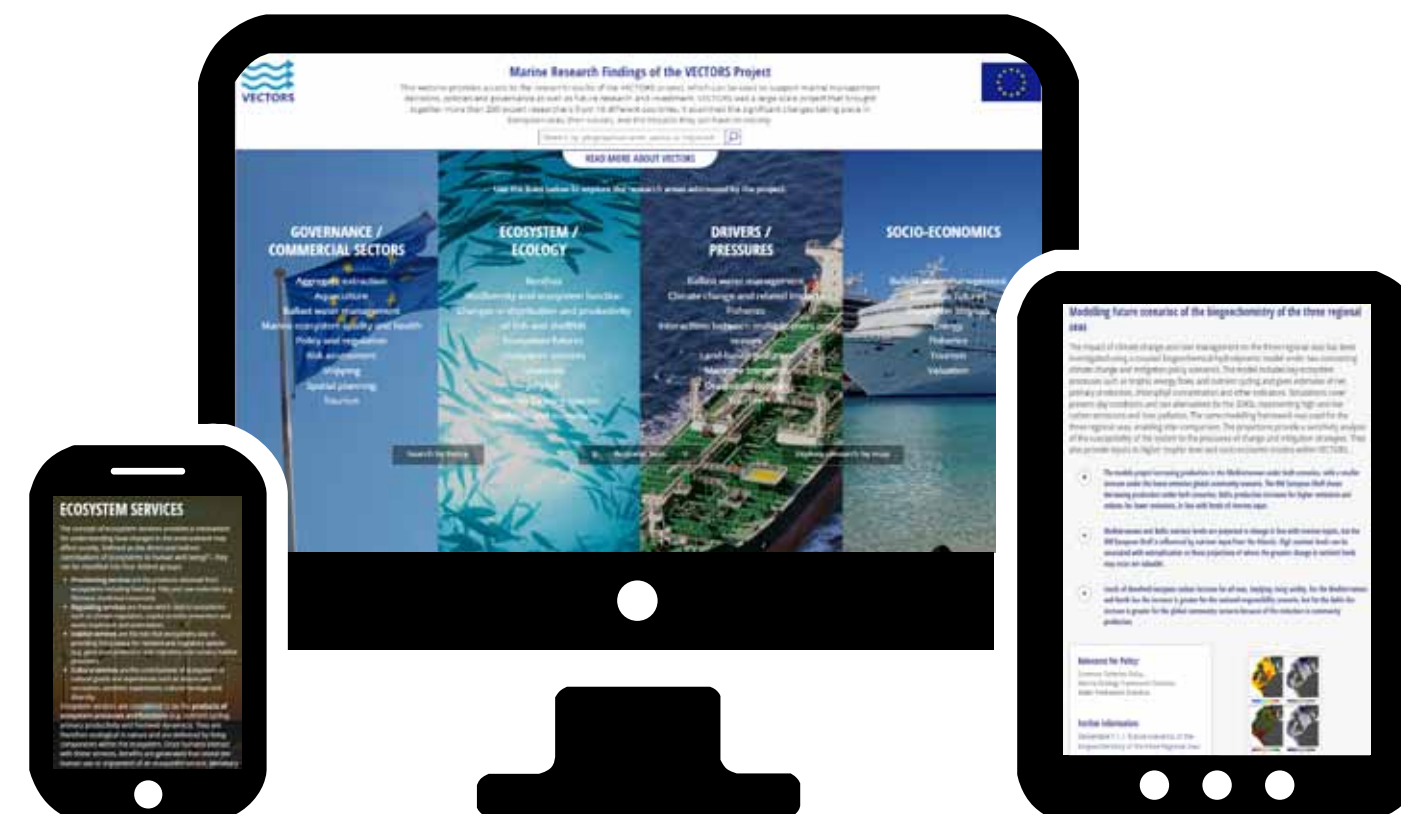
## D6.6 Policy and governance synthesis as a tool for stakeholders

VECTORS provided a policy and governance synthesis to benefit stakeholders and especially those responsible for managing the marine environment. It includes guidance on how to achieve governance solutions to ecological and economic issues identified by the wider VECTORS project including emphasis to marine managers from different sectors on the need for tackling synergistic and antagonistic influences between different marine uses and users. VECTORS has:

- » Reviewed current marine governance at the international, EU and national level, with a particular focus on three key VECTORS themes (renewable energy, fisheries and shipping);
- » Interviewed stakeholders to determine similarities and differences in governance regimes across Europe, identifying lessons learned and examples of best practice;
- » Used scenario analysis to investigate questions such as: Can the governance and legislation currently in place cope with future changes? What current and future instruments will be required and how will they be adapted?;
- » Explored the use of numerical models and their potential to produce outputs for use by policymakers and stakeholders;
- » Developed a method for undertaking risk assessments in the marine environment;
- » Investigated the role of stakeholders in shaping the future of marine governance; and
- » Using best practice from stakeholder feedback, provided policy advice for future marine governance and risk assessment decisions based on scenarios analysis.

## D6.7 Online Synthesis of VECTORS for stakeholders and policymakers

A key output from the VECTORS project is a synthesis website of the project's research results which can be found at <http://www.marine-vectors.eu/>. The synthesis website provides a tool for stakeholders, marine managers and policymakers and advisors to access VECTORS knowledge so that it can be used to support marine management decisions, policies and governance.



All of the VECTORS detailed deliverable reports as well as the scientific publications from the research can be found on the website

**[www.marine-vectors.eu](http://www.marine-vectors.eu)**



# Project Impact

**VECTORS outcomes support marine governance and provide solutions for stakeholders in all marine sectors.**

To achieve the sustainable exploitation of our oceans is one of the great challenges of our time, as oceans have the potential to support substantial parts of our growing demands on transport, for food and energy supply as well as tourism. However, anthropogenic activities exert an increasing environmental pressure on the oceans threatening marine ecosystems and their capability to provide these and other goods and services.

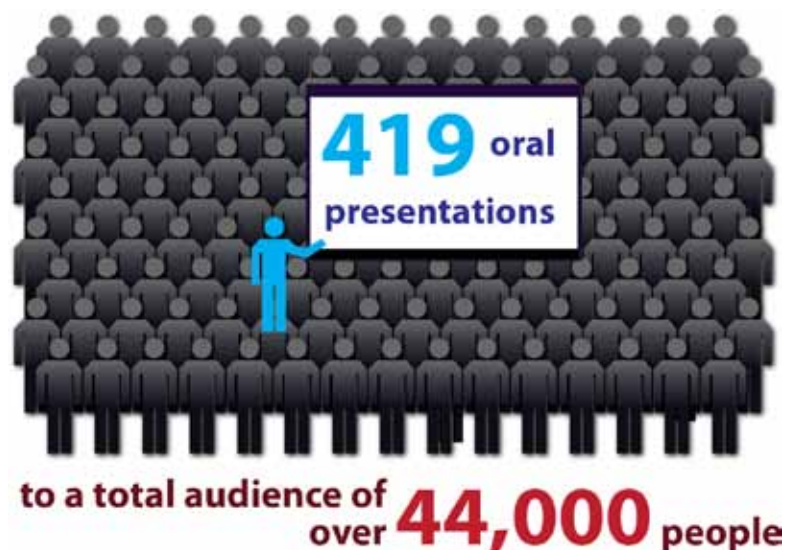
## Mobilising interdisciplinary EU research expertise

The interdisciplinary VECTORS project has mobilised expertise across Europe, integrating a critical mass of marine ecologists, fisheries scientists, statisticians, system modellers, economists, environmental economists and cultural anthropologists. These were experts in marine ecosystems, fisheries, maritime transport, tourism and coastal development, and included those involved in policy support roles through e.g. CIESM, EU, HELCOM, ICES, IMO, OSPAR. VECTORS has thus supported Europe's international leadership in responding to the multiple drivers affecting the marine environment, the multi-sectoral impacts on marine life, and the resulting ecosystem and economic impacts, from an end-to-end perspective.

The outcomes of VECTORS support marine governance and provide solutions for stakeholders in all marine sectors. VECTORS has strengthened European cooperation providing research support to underpin ecosystem based marine resource management from across the scientific community. By applying an interdisciplinary approach based on a multi-sectorial partnership, VECTORS provided its anticipated impact specifically to:

*improve our understanding and the predictive capacity concerning how marine ecosystems respond to a combination of natural and anthropogenic factors* by in depth reviews of pressures and drivers of change, analyses of mechanisms by which pressures and their interactions cause change, description and quantification of impacts and interactive effects of those changes with focus on three regional seas used as test beds for improving understanding and quantitative capabilities.

*understand how rapid environmental changes will affect the full range of goods and services provided by the oceans and the measures that could be developed to mitigate or adapt to these changes* by hindcasting and forecasting impacts of changes under different interacting scenarios and testing management strategies to adapt or mitigate to the changes, and finally integrating and synthesising results for policymakers and stakeholders with the aim of formulating feasible adaptive management strategies.



## Research that supports policy

The EU's overarching policy, aimed at developing a thriving maritime economy in an environmentally sustainable manner, needs to be supported by excellent marine scientific research. An impact of VECTORS has been to deliver integrated marine and maritime research in support of the various EU and international maritime and marine policies, Directives and other legislation. VECTORS has addressed system complexity and interactions through enhanced integration of knowledge and research. It has bridged boundaries between science and policy-making, scientific disciplines and industrial sectors. Research has sought to support new forms of governance by seeking consensus among all concerned parties and establishing continuous dialogue throughout the project particularly between scientists and policymakers but also industry sector stakeholders and representatives from society.

VECTORS has followed an inter-disciplinary and multi-sectorial approach with research directly addressing the needs, particularly in support of the EU Marine Strategy Framework Directive (MSFD), that were apparent at the start of the project:

- » for better assessment of the impacts of climate change on oceans and on coastal areas;
- » for improved understanding of the impact of human activities on coastal and marine ecosystems and their management, including mitigation of the cumulative effects of maritime activities;
- » for tools and understanding to support implementation of an ecosystem approach to resource management and spatial planning to help optimise the management of marine and maritime activities and their sustainable development;
- » for more knowledge on the functional role, evolution, protection and exploitation of marine biodiversity and
- » for further advancement in the development of operational oceanography, with a view to improving prediction on the sea state and dynamics, assessment of risks.

Additionally VECTORS has provided understanding, knowledge and tools relevant to the EU Integrated Maritime Policy (IMP) to move toward an integrated vision for the future management of its oceans and seas based on multidisciplinary scientific knowledge and modern technology. VECTORS has considered areas relevant to IMP such as how decision making and the conciliation of competing interests in marine and coastal areas can contribute to sustainable ecosystems and at the same time to development of economic activities.

## Managing living resources sustainably

VECTORS has improved understanding of productivity and distribution of living resources and provided better models and tools to support the Common Fisheries Policy (CFP) to ensure exploitation of living aquatic resources that provides sustainable economic, environmental and social conditions in a long-term perspective. VECTORS models have been applied for scenario forecasting of ecosystem dynamics, specifically to isolate the response to management measures and to evaluate the economic consequences of fisheries and ocean management measures in relation to other sectorial activities. This is being used to support development of adaptive management systems and is supporting the work of advisory organisations such as ICES. An online tool has been made available via the Google Earth interface to compare modelling results with ICES validation data and various model results are available via the VECTORS interface, often with animations over time.





### Implications of invasive and outbreak forming species

VECTORS has improved understanding of the causes and consequences of outbreak forming species, such as jellyfish, and invasive alien species providing better models and tools to support the MSFD, the forthcoming Alien Invasive Species Directive and EU implementation of the IMO Ballast Water Management Convention. These include the Aquanis database of aquatic non-indigenous species, adopted by ICES; a DNA/Tissue repository bank for OFS and IAS; ballast water management risk assessment and decision support systems which have been of particular interest to HELCOM and OSPAR. Risk assessment approaches have been developed and applied for the first time to marine environmental issues in case studies of marine renewable energy and fisheries.



### Inputting policy and industry related advice

Advances in modelling gained through VECTORS have been communicated to the ICES Working Group on Integrative, Physical-biological and Ecosystem Modelling chaired by WP4.2 leader Prof. Myron Peck. Many VECTORS scientists have input into ICES and other advisory bodies such as OSPAR, HELCOM and CIESM and into high level meetings and conferences attended by policymakers and stakeholders. Examples include: working groups (WG) such as ICES/HELCOM WGIAB Integrated Assessment of the Baltic Sea, ICES/IOC/IMO WG Ballast and Other Ship Vectors, ICES WGITMO Introduction and Transfers of Marine Organisms, ICES WGINOSE Integrated Assessments of the North Sea, ICES expert group workshops (e.g. WKROUND, WKSTAGES); CIESM Scientific Committee Living Resources and Marine Ecosystems and CIESM programs: Exotic Species and Jellywatch, and EU STECF Scientific, Technical and Economic Committee for Fisheries Expert WG meetings; Marine Strategy Coordination Group (MSCG) MSFD meeting; European Environment Agency workshop on Marine Ecosystem Services; Community of European Shipyards Associations/European Ships and Maritime Equipment Association Research, Development & Innovation meetings; EUROCEANS meeting; Ocean of Tomorrow Meeting. Via project partner the Community of European Shipyards Associations (CESA), VECTORS has been affiliated with the Waterborne Technology Platform, and a key partner in Waterborne, is a partner in VECTORS.

Many partners play major roles in policy support at international, European and national levels. Wherever relevant and possible they will use the opportunities of these roles to disseminate VECTORS related information. VECTORS partners leveraged their local and international positions and influence in order to publicize the outcomes of the project as widely as possible. As well as close contact with and dissemination to policy organisations and advisory bodies, VECTORS consulted with stakeholders, such as energy, fishing and shipping industry and industry associations, NGOs and the wider public to achieve communication with a wider stakeholder base. For example, VECTORS scientists wrote to UNEP/MAP to express concern, based on knowledge gained through the project, at the exclusion of species introduced through the Suez Canal into the Mediterranean Sea in UNEP MAP "Draft Decision on the Ecosystems Approach including adopting definition of Good Environmental Status (GES) and targets". This clause has since been removed. Similarly, some VECTORS scientists have published a letter of concern (in the journal Biological Invasions) as well as signing an open letter to warn against the Egyptian project of doubling the Suez Canal without an Environmental Impact assessment to mitigate Lessepsian introductions that will increase IAS in the Mediterranean. This has gained media attention and been acted on by NGOs such as the IUCN as well as Commissioner Velia at DG Environment. In December 2014, the Project Coordinator and the WP6 leader gave oral evidence to the UK Parliament's House of Lords EU Committee as part of their EU Regional Marine Cooperation inquiry and information from VECTORS has been included in its recently published report "The North Sea under pressure: is regional marine co-operation the answer?"

### Communication with key stakeholders

A key point of engagement was via the VECTORS Reference User Group (RUG), consisting of external experts representing stakeholders and users of VECTORS research, who provided advice and guidance on the project orientation. Discussions with the RUG, during the whole lifecycle of the project, have helped to ensure that the tools and strategies developed within VECTORS meet the immediate needs of the maritime community.

VECTORS produced a deliverable report 'Policy and governance synthesis as a tool for stakeholders', which included policy recommendation for Governance Controls, Assessment Tools and Vectors of Change. In this context, governance is regarded as the policies, politics, administration and legislation required to inform and manage the marine environment. The report presents original VECTORS research which was discussed with marine stakeholders throughout the project. By engaging with stakeholders VECTORS was able to disseminate its research and at the same time take advantage of feedback to improve outputs and outcomes of VECTORS research. For example, stakeholder feedback was utilised in the production of the policy recommendations, assessment tools and policy scenario analysis for the key vectors of change associated with fisheries, marine energy and shipping.

Stakeholder input was obtained from a series of semi-structured interviews at a geographical case study level in the VECTORS regional seas and also at the EU-level. A marine stakeholder workshop was organised to obtain stakeholder feedback to improve our current understanding of and stakeholder wishes for marine governance and learn from examples of best practice in order to better advise on future policy and risk assessment decisions based on scenarios analysis.



### Public and commercial implications

VECTORS research has impacted directly on the public. A considerable amount of marine ecosystem service and economic impact valuation research has required engagement with the public through face-to-face and internet surveys as well as focus groups. Furthermore, our research on outbreak forming species in the Western Mediterranean has involved high profile public information campaigns, such as Jellywatch and the iPhone application 'iMedJelly' produced in VECTORS. Jellywatch citizen science campaigns were carried out in Italy, Spain and Israel throughout the project. This activity led to an expansion in the number of records (over 15,000 records) and of the distribution range of OFS and IAS, as well as to the discovery of a new species to science (*Pelagia benovici* n. sp.). The information campaigns have helped to lower the impact of jellyfish on bathers by increasing the public's awareness of jellyfish and teaching them how to identify between those that sting and those that are safe. Studies have shown that despite an increase in jellyfish occurrence in coastal waters there has been a decrease in the number of people using first aid centres in areas where these campaigns have taken place. Furthermore, VECTORS scientists are using their research to feed into other projects and campaigns that are looking at mitigation measures, such as the use of anti-jellyfish nets in coastal waters to prevent blooms reaching bathing areas. Through its creation of the World Jellyfish Patents (WJP) database, which collates available information on international patents on jellyfish utilization in different fields, VECTORS has identified potential socio-economic benefits from jellyfish harvesting that could have far reaching implications for food, health and industry so that we no longer need to look on the number of increasing jellyfish as a management problem but also an opportunity.



### Spreading scientific excellence and training

VECTORS research has been directly aligned with the strategic marine science research programs of the participating nations and also their ongoing monitoring activities in support of e.g. MSFD assessments and activities and fisheries assessments.

VECTORS has spread scientific excellence through publications in high ranking scientific journals and presentation of results at relevant high profile meetings. There have been 187 journal articles of which 119 were first authored by VECTORS scientists (Figure 1) as well as 8 book chapters and 1 book.

The project has employed and trained the best available young researchers, following the best practices of the partners. Contributing towards the education of the next generation, multiple training activities have been undertaken. These include a summer school on 'Ecosystem goods and service quantification and valuation methodologies' for young researchers to be trained through theoretical lectures and practical exercises. In total 42 PhD students participated in the VECTORS project in some way with more than 67% partially funded through VECTORS.

### Presenting VECTORS externally

VECTORS has been presented to audiences across the world (Figure 2). The dissemination activities have taken a wide variety of forms (Figure 3) and whilst dominated by scientists, the audience has ranged from policymakers to industry and civil society (Figure 4). In total there have been 419 oral presentations that included VECTORS material to a total audience of nearly 45,000 people.

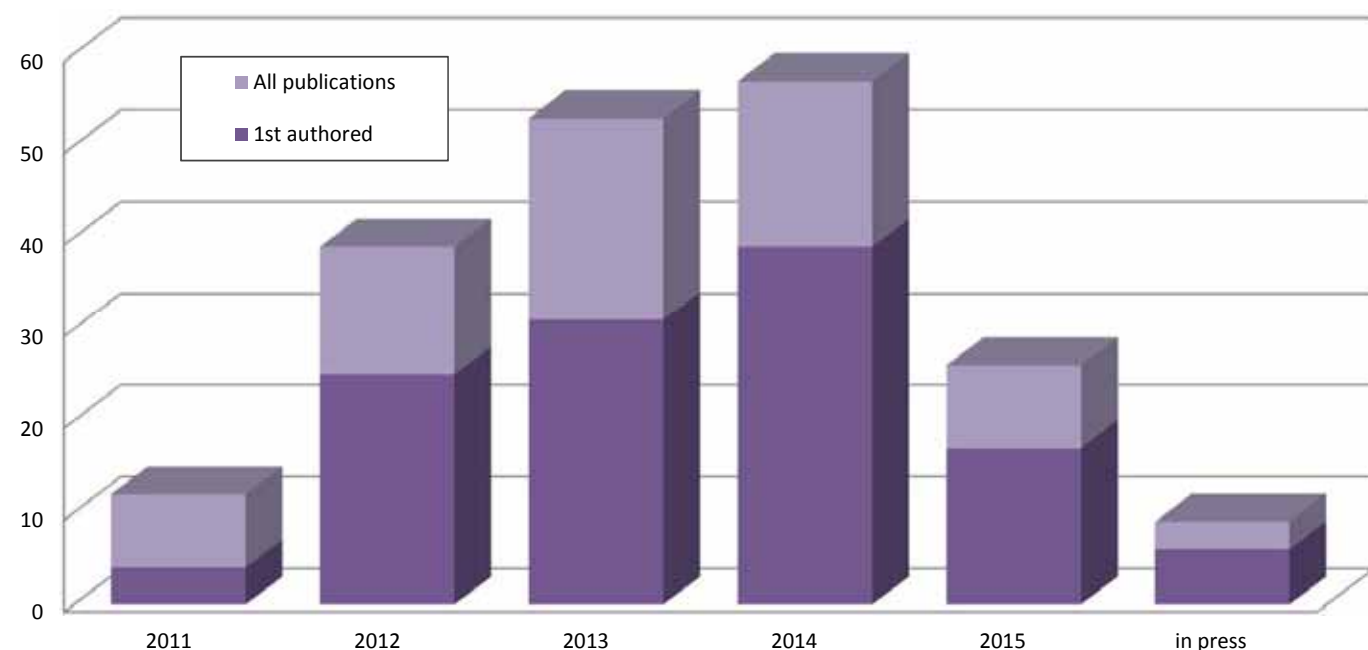


Figure 1 Number of VECTORS publications in refereed journals (as of 20/3/2015)

Figure 2 Numbers of dissemination activities by audience location.

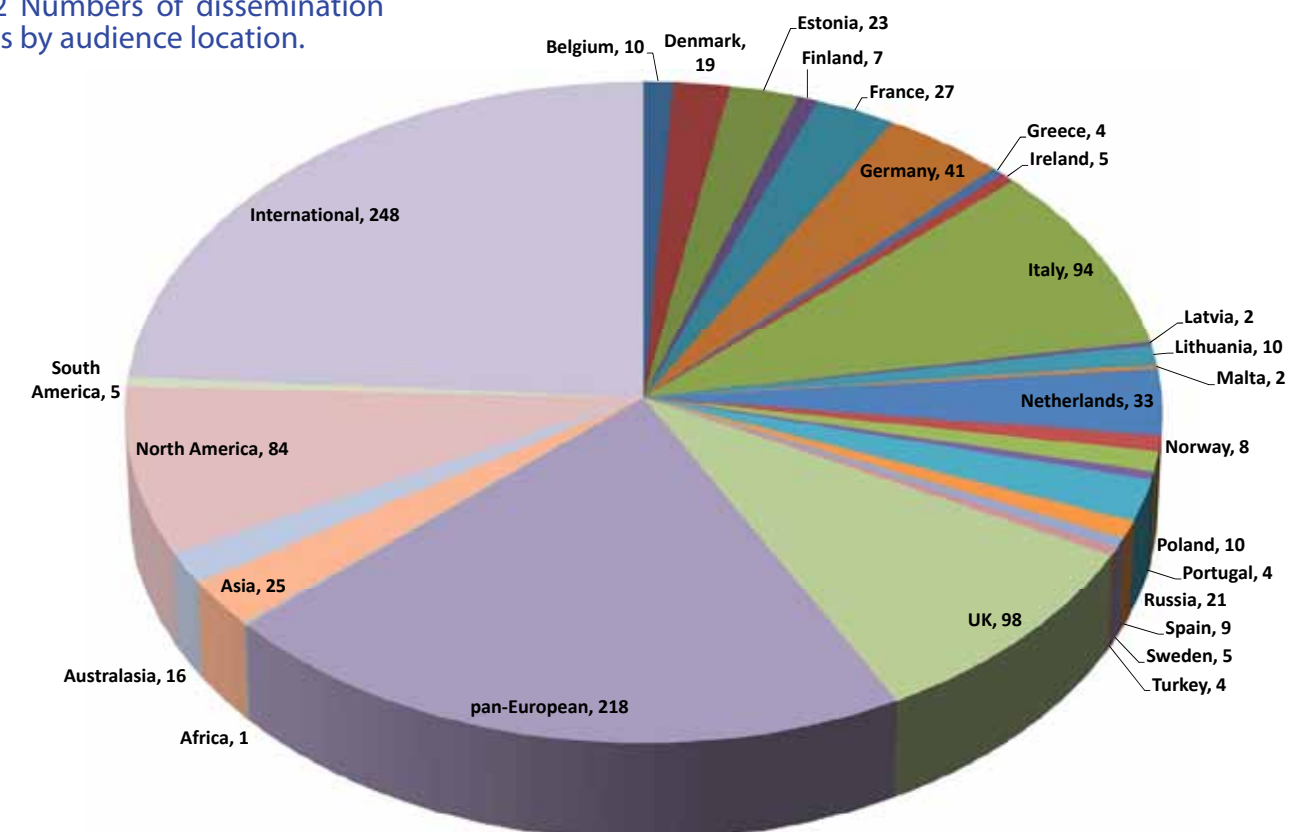


Figure 3 Number of dissemination activities by type

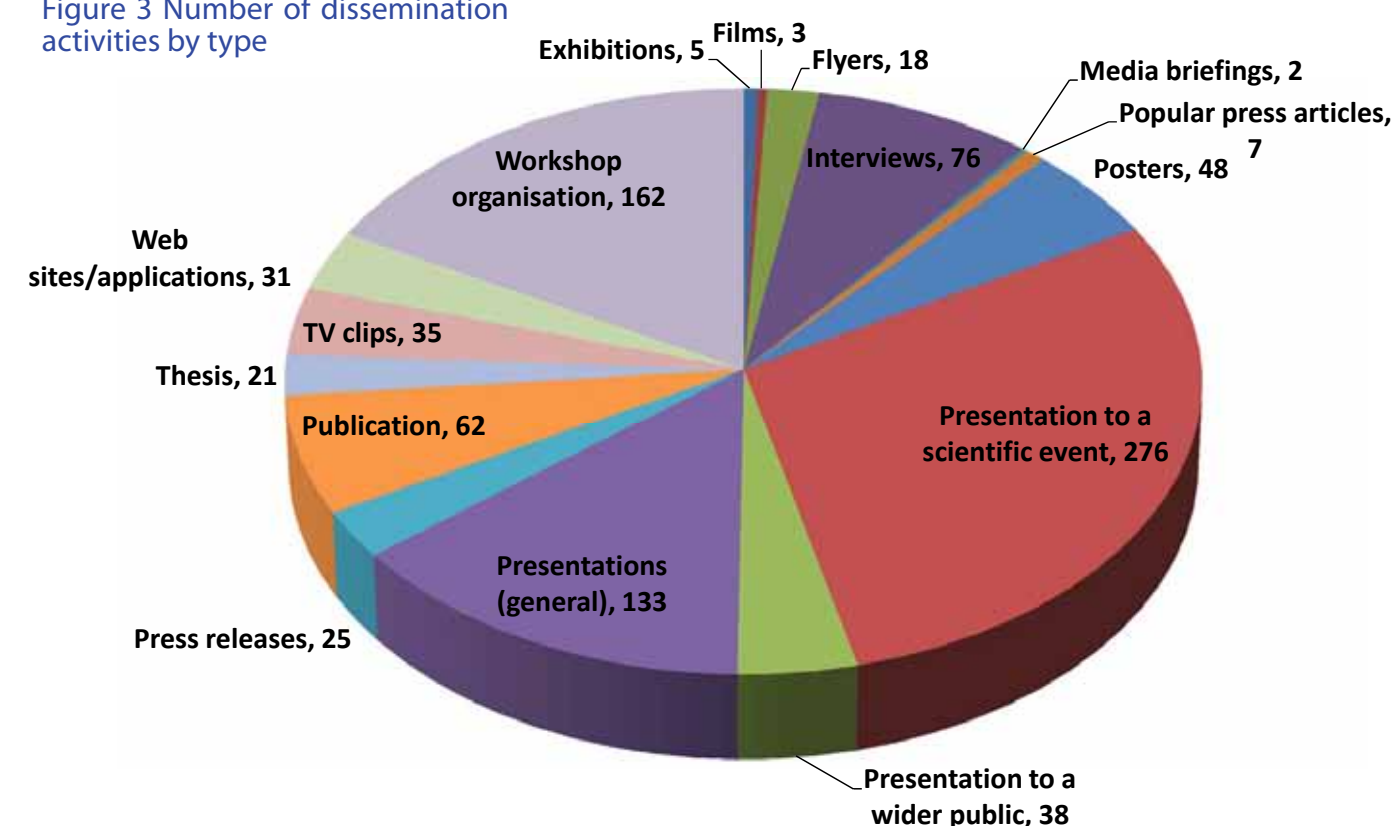
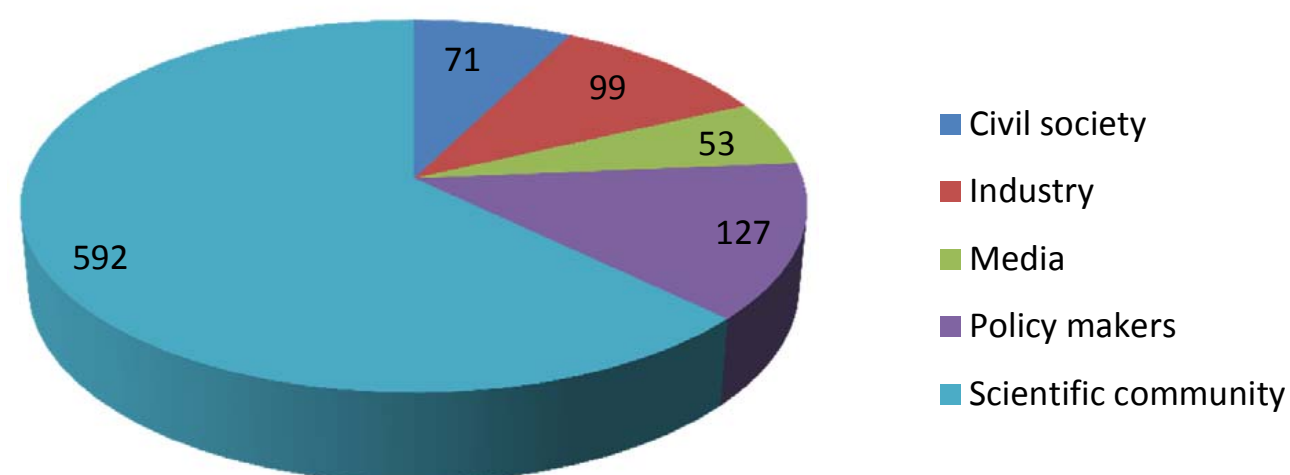




Figure 4 Number of dissemination activities by audience type



### Main dissemination activities

Plymouth Marine Laboratory (PML) delivered effective dissemination and communication for internal and external audiences throughout the VECTORS project. Understanding the importance of these tasks for ensuring integration within the project and increasing the impact of the project's findings, PML delivered a wide range of activities to support the achievement of the project's objectives. Internal communication between project partners contributed to the effective delivery of collaborative project tasks, which was particularly important in such a broad, interdisciplinary project with a large number of participants from 16 different countries. Externally facing dissemination allowed the consortium to share opportunities, results and resources with the wider marine science community as well as stakeholders.

In terms of internal project communication, this was largely achieved through annual project meetings, integrating workshops, remote conferencing and Basecamp. More outward facing communication channels were utilised for external communication through the project website, newsletter, leaflet, factsheets and policy postcards as cost-effective and openly available tools, which also supported communication between partners.

### Database of agencies, SMEs and individuals to facilitate the transfer of VECTORS results

A key initial task of the project was to create a database of relevant contacts for project partners to use to disseminate VECTORS knowledge to interested / relevant organisations / individuals. This was available throughout VECTORS on the project VECTORS website for partners to use. The database contains contact details for VECTORS relevant external organisations, stakeholders, policymakers etc. It was a project tool to help partners disseminate VECTORS generated knowledge to the relevant people. The database is easy to use, with simple search criteria, and was easily accessible to all partners.

The database was continuously updated throughout the project and, as of January 2015, contained more than 460 contacts. This database ensured that the project was networked effectively with its constituencies. The database was a key deliverable of WP7 but was relevant to all other work packages as it aided the dissemination of VECTORS knowledge.

### Project Website

From the beginning of VECTORS a project website was available that provided a key tool for facilitating the dissemination of results. The website brought together and showcased the developing research findings of the project as it progressed; provided useful information for partners, such as reporting guidelines; and made reports, deliverables, event information and much more widely accessible.

The dissemination pages of the website focused on transferring VECTORS knowledge through a wide range of mediums that continue to make the research accessible at a range of levels and through a choice of tools. At the most basic level the VECTORS leaflet provides an overview of the project that is very accessible to all stakeholders as well as the general public, while fact sheets provide a more in-depth account of specific areas of scientific research conducted. Scientific papers and Research Highlights provide the greatest level of detail about research activities and the results achieved. Development of the VECTORS website to include Dissemination / Knowledge Transfer pages (Deliverable 7.2) ensured that the website facilitated the transfer of research-based knowledge to inform and influence policy decisions. These additional pages of the website provided the framework for compiling all of the Knowledge Transfer tools that were generated by the project in one accessible location, such as factsheets. They therefore grew and developed with the project and eventually contributed to the achievement of Deliverable 7.4

Towards the end of the project the focus of the website changed from being a site providing information about the project to one that was designed with the clear purpose of presenting the project's findings. This synthesis of the project findings was formatted in a way that was particularly aimed at policymakers and stakeholders. The Synthesis Website was launched on 31 January 2015 (D6.7) and took the place of the Project Website. The decision was made to replace the website, rather than keep both, in order to ensure all traffic was directed to the Synthesis Website as this became the priority dissemination site for VECTORS' research. Much of the information from the Project Website (Publications, Deliverables, Factsheets etc.) is available on the new site and has been linked directly to the research findings presented to ensure an integrated web of information that is easy to navigate and access. Since its launch at the end of January there have been 1,638 unique users of the synthesis website, 2,197 sessions and 7,675 page views (as of 16 March 2015).

### VECTORS Products: Factsheets, Policy Postcards, Newsletters and the Project Leaflet

Factsheets produced throughout the VECTORS project provided concise overviews of key VECTORS science in order to highlight particular research topics, findings or case studies in a stand-alone document with some available in multiple languages. They are a high profile communication tool that disseminated VECTORS' science to relevant audiences with electronic and printed copies available. In total, 26 factsheets were produced throughout the project covering: an overview of the VECTORS project; the drivers of change investigated in D1.1 and D1.2; the case studies conducted in the regional seas work packages; and more general topics such as jellyfish, marine stakeholder engagement and invasive alien species. Due to the multidisciplinary nature of the project the factsheets provided an internal communication tool to share research across disciplines and work packages within VECTORS as well as an external communication tool to disseminate VECTORS research to stakeholders, other academics and the policy community.



VECTORS Factsheets





Six Policy Postcards were produced and disseminated to stakeholders, policymakers and managers throughout the project. Printed versions were sent to the contacts from the database and also provided to partners to disseminate at meetings and events. The postcards provided a snapshot of project progress to keep interested parties regularly informed without overburdening them with too much detail that can lead to products such as this being overlooked. The postcards provided the project headlines to engage readers in VECTORS science in the hope that they will then visit the synthesis website for further information.

Project newsletters were produced on a biannual basis, with seven issues produced in total, in order to share up-to-date and relevant news with the VECTORS community. They included research highlights, project updates and event information and were disseminated to partners and the KT database and were made available on the project website.

A project leaflet was produced during the first reporting period and updated in the subsequent two periods in order to ensure it was up-to-date. The leaflet provided a general overview of the project that provided an introduction to the research aims, purpose and approach. Copies were made available to partners to disseminate at meetings and conferences and they were regularly sent to relevant events and exhibitions, such as the Irish Sea Symposium, when requested.

All of the products described were designed to provide succinct information that is engaging and easy to read, with accessible language with the hope that they would appeal to academic audiences as well as interested members of the general public with less background knowledge of the subject. All of the communication tools are available to download from the VECTORS website at <http://www.marine-vectors.eu/Products>

## OpenEarth

Deltares led the data management within the project to ensure the standardization of data formats and dissemination of results internally to VECTORS across all work packages and across all project participants, including sectors. This was achieved by developing tools, techniques and methodologies, as well as supporting and training the project's contributors to tailor their own data to meet the international standards and interoperability that OpenEarth fosters (e.g. netCDF-CF convention) and support uploading and sharing of data. Deltares set up repositories for storage, back-up and version control of raw data, scripts and source code. VECTORS Data Products could then be shared freely via various web based tools.

## Reference User Group Inputs

The Reference User Group (RUG) was an essential feature of the VECTORS project bringing together stakeholders who are likely to benefit from, use or be affected by the findings of the project. It provided an effective mechanism for cooperative working and report review.

The involvement of key stakeholders in VECTORS throughout its lifespan was important to its success. The RUG members represented potential end-users of VECTORS findings, making them relevant critics and advisers. The presence of RUG members at project meetings was invaluable, providing essential feedback that helped the researchers to consider the application of their science. It is recommended for future projects that wish to engage with the policy community to include a RUG as it had a positive impact on the VECTORS project. However, researchers also need to be supported by helping them to understand how their findings could be applicable to potential end-users, for example by providing information on relevant legislation and management frameworks as well as tools to disseminate their science, thus ensuring that their findings will be applicable.

## Scientific Publications

As of January 2015, more than 180 scientific articles have been published in peer reviewed journals as of result of VECTORS' research. All of which are listed in an EndNote database managed by PML, which includes PDF versions.

In addition, a searchable database has been included on the VECTORS Synthesis Website ([www.marine-vectors.eu](http://www.marine-vectors.eu)) providing an open access list of all of the publications with links to the journal website where the full articles are available. Users of the website can search by author, key word, title or date to find related papers of interest. The publications are also directly linked to from the relevant research pages of the site where the key findings are presented.



## Exploitation of Results

The exploitable foreground from VECTORS falls under the category of general advancement of knowledge. It can be broadly categorised as 1) data 2) model code and parameterisations, 3) model simulations, 4) management relevant tools and 5) synthesised information. The knowledge and tools developed in VECTORS will be exploited in a number of ways within the framework of the VECTORS IP agreements. It is anticipated that the exploitation of foreground will be primarily for future research and the partner organisations are already making direct utilisation of the foreground for further research in EC and national funding opportunities.

Synthesised outputs from VECTORS are freely available for use by third parties from the VECTORS website as are most of the project's publications and reports. The original data sets produced in VECTORS are available from the organisations that created them. VECTORS has developed a number of models and model simulations, decision support and risk assessment tools and databases. These address or support management questions in the context of the interactions between climate, fishing, marine renewable energy, tourism, aggregate extraction, IAS and OFS, and also the context of ballast water management. Some of the foreground owning organisations (e.g. DTU, Cefas, Ifremer, vTI-SF, UHAM, DLO, WU, KUCORPI, EMI-UT, DELTARES, SAHFOS) are directly involved in the implementation of the MSFD or advising on CFP at a national level and are making direct utilisation of the foreground for further research. The next steps of exploitation will be the continued practical application and development of such systems to develop management strategies which are robust to changes in environmental drivers.

The SME GoConsult has produced a book on Ballast Water Management and Decision Support Systems in global maritime transport. GoConsult will use decision support tools and risk assessments for ballast water management, developed in VECTORS, in the operation and promotion of their business.



## VECTORS partners

### UK



### Netherlands



### Denmark



AARHUS UNIVERSITY

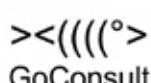
### Italy



### France



### Germany



### Spain



### Belgium



### Lithuania



### Greece



### Ireland



### Israel



### Poland



### Estonia



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